RF 1132

Institute of Polar Studies

Report 2

A Preliminary Report on Plant Remains and Coal of the Sedimentary Section in the Central Range of the Horlick Mountains, Antarctica

by

James M. Schopf

U. S. Geological Survey
in cooperation with
Institute of Polar Studies

Prepared for

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A PRELIMINARY REPORT ON PLANT REMAINS AND COAL OF THE SEDIMENTARY SECTION IN THE CENTRAL RANGE OF THE HORLICK MOUNTAINS, ANTARCTICA

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E R R A T A

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entitled

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p vii, Figure 4: for "Glossppteris", read Glossopteris.

p 1, par 2, line 1: for "resources", read resource.

p 1, par 3, line 6: for "possible ans", read possible and...

p 5, par 5, line 3: for "braching", read crossing...

p 9, par 1, line 2: for "all be altered", read all been altered....

p 15, top line: for "and regards it", read and regards its....

p 26, par 2, line 5: for "anomolous", read anomalous....

p 29, par 4, line 3: for "Srivastava, 1956), Surange and"...., read (Srivastava, 1956). Surange and....

p 35, par 3, line 3: for "purposed", read purposes...

p 36, par 1, line 8: for "craks", read cracks....

p 39, par 2, line 15: for "Temperature", read Temperate....

p 42, par 2, line 5: for "....5 and 8 were the..", read 5 and 8 where the....

p 43, par 1, line 5: for "Hoeg", read Høeg....

p 43, par 1, line 7: for "late Carboniferous", read Late Carboniferous....

p 46, par 1, line 3: for "ans", read and....

p 46, par 3, line 10: for "permian", read Permian....

p 52, par 2, line 12; for "acant information", read scant information...

p 53, par 3, line 6: for "recongnized", read recognized....

p 53, par 3, line 12; for "intrusived", read intrusives....

FOREWORD

This project was initiated as a part of the International Geophysical Year program under the auspices of the U. S. National Committee for the IGY, National Academy of Sciences, and, as such, was supported in part by National Science Foundation Grant No. Y/4.10/285 (Ohio State University Research Foundation Project 825). Because the monies granted were completely expended, final report costs were covered by funds from NSF Grant G13590 (OSURF 1132) which continues the geological study of the central range of the Horlick Mountains. In addition since the subject matter of this report is much more closely related to that of NSF Grant No. G13590 (RF 1132) than NSF Grant No. Y/4.10/825 (RF 825), it is considered appropriate for this report to be included with those concerned with the scientific results of the geology of the Horlick Mountains.

Arthur Mirsky

Arthur Mirsky
Assistant Director

ABSTRACT

The sedimentary section of the central range of the Horlick Mountains includes coal and carbonaceous sediments with a variety of plant fossils. These have been studied to provide information about (1) age of the deposits, (2) coal composition and metamorphism, and (3) general geologic inferences that may be based on the occurrence of coal and fossil plants five degrees from the South Pole. More than 20 types of spore and pollen microfossils have been described briefly. Fragments of fusinized wood are abundant and aid in characterization of the floral assemblage and sedimentary facies. Fossil wood is described in detail for evidence it provides about conditions of growth, woody degradation, and diagenetic mineralization. The wood shows thick annual growth rings which attest to the periodicity of climate and to favorable growth conditions. Fossil leaves and seeds provide further evidence of the nature of the flora and basis for general age determination. Coal has been chemically analyzed and is of semianthracitic rank. Studies of thin and surface sections of coal show features most similar to those of the bituminous coal deposits of Australia, India, and Africa. No evidence is in conflict with Permian age assignment for the Horlick Mountains coal measures deposits, but further study is needed to provide a more detailed basis for correlation.

ACKNOWLEDGMENT

These studies have been carried out by the U. S. Geological Survey, in cooperation with the Institute of Polar Studies of The Ohio State University. All materials from the Horlick Mountains were provided by Mr. W. E. Long who collected them and is working under auspices of The Ohio State University, Institute of Polar Studies, on the general geology of this area. Coal specimens collected by Mr. John Mulligan in the Granite Harbor area of Antarctica, and coal analyses, were provided by the U. S. Bureau of Mines. The technical assistance of Mr. Robert W. Bouman, working in part under Survey and in part under Institute auspices, in preparing the samples and in photographing selected material, has been invaluable for preparation of this report. Some of the plant microfossil material was prepared by Mr. Nelson N. Williams of the Survey.

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INTRODUCTION

This report chiefly presents information about the carbonaceous plant materials from Mount Glossopteris in the central range of the Horlick Mountains, which lies at about 113 degrees west longitude and about 5 degrees north of the South Pole. A variety of plant remains are present in the Antarctic coal measures and all find some representation in the area of this report. Plant fossils are very important in geologic study of Antarctica since fossil animal remains are extremely rare and none has been identified from the extensive Antarctic coal measures deposits.

Coal is the only potentially economic mineral resources discovered thus far on the Antarctic continent. Specimens from two coal beds in the Horlick area were studied, but this coal is highly metamorphosed and not very informative as to the plants that composed it. A better indication of the plants associated with the Antarctic coal measures may be obtained from plant microfossils that can be segregated, not from the coal itself, but from adjacent carbonaceous shale. Variously preserved fossil wood and tree trunks are present. They provide a valuable indication about conditions of plant growth in this area, which is coldest and, in terms of available liquid moisture, actually one of the driest terrestrial environments now known. A small collection of fossil leaves and seeds provides a basis for comparison with fossils of other places in the Southern Hemisphere since these are the most conventional types of plant fossils widely reported. Comparison of the biological characteristics of fossils from deposits newly discovered is the standard means of determining the age of the rocks in which the fossils occur. Larger collections are needed for more definite and precise results, but the forms now available seem to provide a satisfactory preliminary basis for general age determination.

The problems to be solved are essentially threefold. In the first place, age determination is important to establish the sequence of geologic events in Antarctica and for comparison with other continents of the Southern Hemisphere, all of which show striking geologic similarities. At the present time, very little precision in age determination is possible ans one would hope, for example, eventually to be able to tell whether the same sequence of coal beds are represented in the Horlick Mountains which are present 200 miles southwest at Mount Weaver, or beyond at the head of the Beardmore Glacier. Plant microfossils, here reported for the first time from central Antarctia, should be of greatest assistance for this latter work.

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* Publication authorized by the Director, U. S. Geological Survey.

A second set of problems particularly evident in view of the present rigorous Antarctica climate (see Wexler and Rubin, 1961) relates to determination and satisfactory explanation of climate and ancient environments, their sequence in time, and influence on the sedimentary deposits. The preservation of plant material reflects environment at the time of deposition and on early diagenesis. It also determines the selection of methods appropriate for preparation of material for detailed study. Procedures in preparation and modes of preservation are reported to aid in evaluating the evidence of depositional environment and diagenesis afforded by this study. A third group of problems concerns tectonic history and metamorphism. Since information about these fields of study, also, devolves upon the present condition of the rocks and their attitudes above and below the ice, all these studies are complementary to the study of ancient environments.

All three sets of problems are also complementary for development of potential mineral resources. Many considerations pertinent for mining in Arctic regions (Queneau, 1961) apply similarly to the Antarctic. Antarctica may still show useful concentrations of valuable minerals and petroleum. With so much of the terrian buried beneath the polar ice cap, refined methods of geologic investigation are necessary to guide successful future prospecting. Not least important is the bearing of Antarctic geology upon fundamental problems of general significance, such as continental drift or migration of the poles. An integrated study of the various plant fossil materials seemed desirable because all kinds contribute and complement one another in various ways toward resolution of each of the sets of problems.

GENERAL GEOGRAPHIC AND GEOLOGIC SETTING

Ordinary geographic reference in Antarctica tends to be confusing because of proximity to the Pole. Both latitude and longitude must always be considered and points of very different longitude may not be very far apart. The continent consists of two unequal physiographic and geologic provinces, as shown by the map in Fig. 1. The larger province, called the East Antarctic Shield because its locations are dominantly east longitude, fronts toward Australia, the Indian Ocean, and South Africa. It extends westward from the western side of the Ross Sea embayment, just south of New Zealand, all the way around the main land mass of the continent to the eastern side of the Weddell Sea embayment (actually south of South Georgia in the South Atlantic). East Antarctica shows little evidence of folding since Precambrian time. Areas of sedimentary rocks generally show beds flat lying, although displacement occurs by block faulting or as a result of the intrusion of igneous dikes and sills.

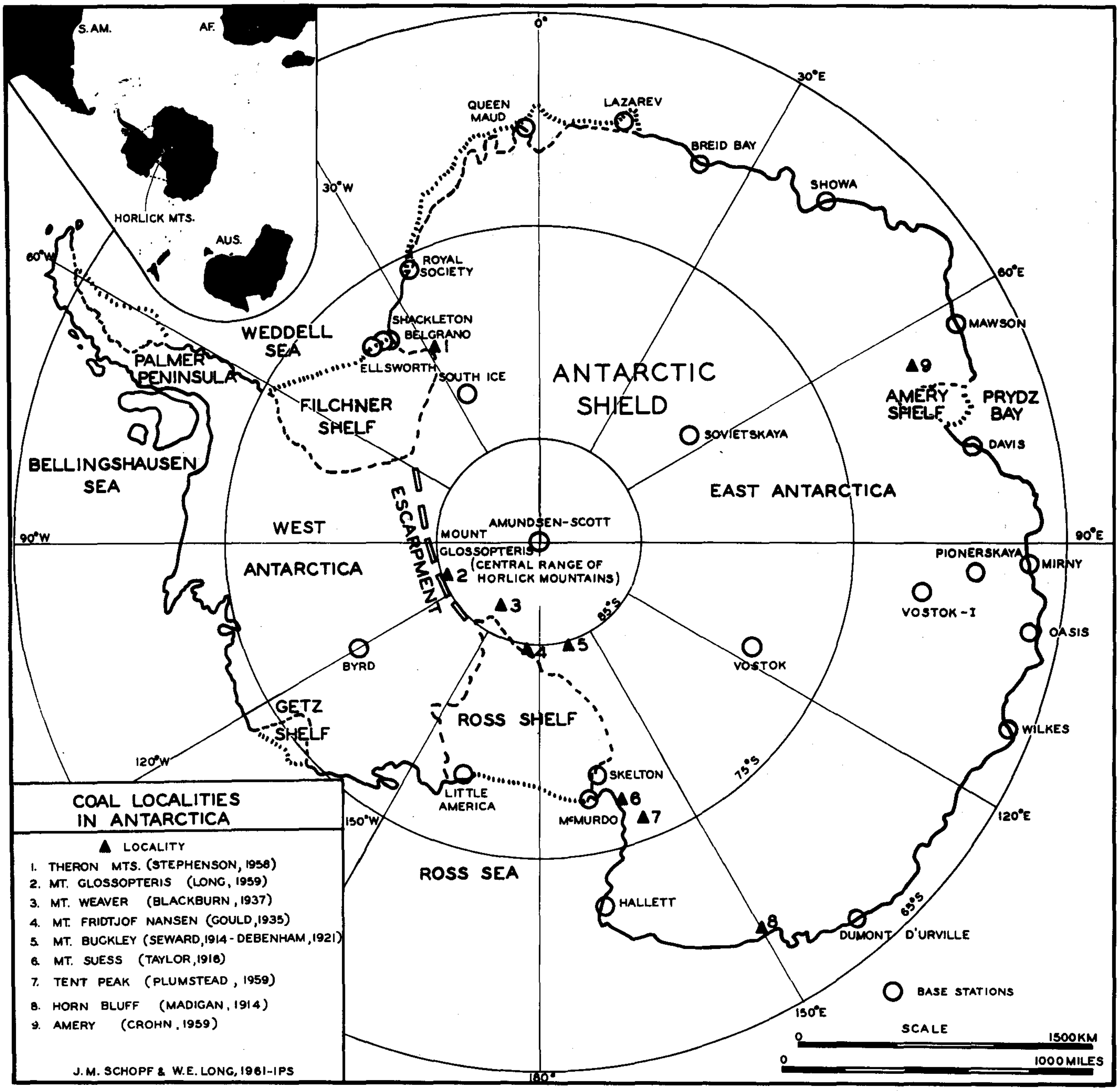
S. AM.
AF.
HORLICK MTS.
AUS.
WEDDELL SEA
PALMER PENINSULA
FILCHNER SHELF
BELLINGSHAUSEN SEA
WEST ANTARCTICA
ANTARCTIC SHIELD
EAST ANTARCTICA
ESCARPMENT
MOUNT GLOSSOPTERIS (CENTRAL RANGE OF HORLICK MOUNTAINS)
AMUNDSEN-SCOTT
ROSS SHELF
GETZ SHELF
ROSS SEA
AMERY SHELF
PRYDZ BAY
QUEEN MAUD
LAZAREV
BREID BAY
SHOWA
MAWSON
DAVIS
SOVIETSKAYA
PIONERSKAYA
MIRNY
VOSTOK-I
OASIS
VOSTOK
WILKES
DUMONT D'URVILLE
HALLETT
SKELTON
McMURDO
LITTLE AMERICA
BYRD
SOUTH ICE
ELLSWORTH
SHACKLETON
BELGRANO
ROYAL SOCIETY
COAL LOCALITIES IN ANTARCTICA
LOCALITY
1. THERON MTS. (STEPHENSON, 1958)
2. MT. GLOSSOPTERIS (LONG, 1959)
3. MT. WEAVER (BLACKBURN, 1937)
4. MT. FRIDTJOF NANSEN (GOULD, 1935)
5. MT. BUCKLEY (SEWARD, 1914 - DEBENHAM, 1921)
6. MT. SUESS (TAYLOR, 1916)
7. TENT PEAK (PLUMSTEAD, 1959)
8. HORN BLUFF (MADIGAN, 1914)
9. AMERY (CROHN, 1959)
J.M. SCHOPF & W.E. LONG, 1961-IPS
BASE STATIONS
SCALE
0 1500KM
0 1000 MILES
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
85°S
75°S
65°S

Fig. 1

The smaller western province of Antarctica (west longitude) may be mostly an icebound archipelago and not part of the Shield. It includes folded mountains within the smaller arc extending eastward from the eastern side of the Ross Sea (long 155°W.) to a point south of Patagonia where the Palmer Peninsula extends northward, and extends southward to about the latitude of the Horlick Mountains, 5 to 8 degrees north of the South Pole. The eastern margin of the East Antarctic Shield province is the eastern shore of the Palmer Peninsula, which may also be described as the western shore of the Weddell Sea.

The central margin of the East Antarctic Shield may be visualized as an arcuate line overlapping a few degrees beyond the Pole, continuing from the trend of the western shore line of the Ross Sea, to the eastern shore line of the Weddell Sea. This line approximates the prominent escarpment, of which the central Horlick range is part, and forms the inland margin of the Shield. The Antarctic escarpment has been best outlined recently by traverses from Byrd Station led by C. R. Bentley (see Bently and others, 1960). The escarpment and block faulted mountains back of it have been called the Antarctic horst by David and Priestley (1914) and by Gould (1935).

The central range of the Horlick Mountains, including Mount Glossopteris with which we are mainly concerned, is located near the center of the major escarpment (lat 84°44' S.; long 113°44' W.) and, accordingly should be regarded as in the eastern Shield province, although it is about 5 degrees north of the Pole and just south of the smaller territory properly included in the western province of the continent. This area is indicated on the reference map (Fig. 1) together with the other known coal localities and locations of well-known Antarctic bases. Some of the other coal localities have provided analytic information discussed in this report.

SAMPLES STUDIED

Specimen collections listed below were all obtained by Mr. William E. Long on December 6, 1958. A description of the general stratigraphic section in the central range of the Horlick Mountains has been given by Long (1959a, 1959b, 1960) and locations and stratigraphic relations are according to his sketch map and personal communication with Mr. Long. All samples are from the coal measures of the Beacon Sandstone. The Beacon Sandstone was named by Ferrar (1907) from exposures west of McMurdo Sound in South Victoria Land. It has recently been suggested (Harrington, 1958) that the extensive sequence of rocks referable to the Beacon should be elevated to rank as a system, and that group (and formation ?) names should be applied to local subdivisions. Long's continued work in the central range of the Horlick Mountains indicates further the desirability of this procedure.

The list includes physical description of the samples examined, sample numbers referring to Long's published section, and the maceration numbers used for reference to permanent preparations containing microfossils. Distances have been estimated from the summit of Mt. Glossopteris.

H-6 (Mac. 935) Mudstone or shale, sandy, gray, moderately hard, with horizontal worm (?) tubes. On top of long, flat ridge, approximately 1000 feet above granite, about 3-1/2 miles west of Mount Glossopteris.

H-8 (Mac. 928) Shale, flaky, dark, sandy, marked fissility but probably poorly bedded, soft. Near bottom of open slope about 100 yds. southwest of ridge top; about 200 feet higher in section and about 1000 feet east of H-6, about 3 miles west of Mount Glossopteris.

H-10 (Mac. 929) Shale, silty, gray, moderately soft; below first coal and above fault zone; about 150 feet above top of massive sandstone, about 2000 feet east of H-8 and 2-3/4 miles west of Mount Glossopteris.

H-10-1/2 (Mac. 946) Sandstone, gray, weathering buff, thinly laminated, crossbedded, micaceous, top of laminae often abundantly carbonaceous, with undulant and braching invertebrate animal trails on some bedding planes. Such trails are common on the dip slope of rocks along the spur ridge. Below Quartz Pebble Hill, about 200 feet stratigraphically and 500 yds. up slope above sample location H-10, at an obvious break in the slope, about 2-1/2 miles west of Mount Glossopteris.

H-14 Sandstone, coarse, light buff, with fusinized edge of plant axis, showing siliceous veinlets in cross checking. Associated with second coal about 300 feet above first coal bed, about 2-1/4 miles west of Mount Glossopteris.

H-15 (Mac. 932) Quartz pebble sandstone, moderately to poorly cemented, light buff, with coalified wood, limonitic in part, only slightly compressed, showing portions of at least four growth rings. About 500 feet south of H-14, about 30 feet above second coal bed.

(Samples H-12 through H-15 were taken in sequence above the flat-topped ridge up Quartz Pebble Hill.)

H-16 Coal, thin-banded, cleat moderate but well oriented, with thin lenticles of fusain, attrital matrix moderately dull. Detailed location in question; probably close to that of H-20.

H-18 (Mac. 930) Shale, dark, thin-bedded, moderately soft. About 120 feet above second coal, about 700 feet south of H-16 and 2-1/2 miles west-southwest of Mount Glossopteris.

(Samples H-16 through H-18 taken along top of Quartz Pebble Hill on the edge of the "inner plateau.")

H-19 Wood, solidly silicified, partly compressed but showing clearly distinct growth rings. Below third coal bed, about 8000 feet east of H-18 and an estimated 1000 feet higher in section, about 3/4 mile southwest of Mount Glossopteris.

H-20 (Mac. 923) Coal, thin-banded, fusain present, in part bony and impure. About 7000 feet slightly west of north from H-19, but probably at about the same stratigraphic level, < 3/4 mile slightly north of east from Mount Glossopteris.

H-21 Wood, solidly silicified, partly compressed, showing about 35 thin, concentric rings. Specimen found *in situ* but stratigraphic level not indicated; probably about 3/4 mile southwest of Mount Glossopteris.

H-22 (Mac. 933) Mudstone, light gray, noncalcareous, thin- and even-bedded, disturbed by possible slump structures. Below upper coal beds, possibly about 600 feet above third coal bed of H-20. About 1/2 mile southeast of H-20, about 1/4 mile northeast of H-19, about 1/2 mile south-southwest of Mount Glossopteris.

H-23 (Mac. 934) Sandstone, gray, moderately hard, including coarse stems, partly compressed, partly coalified and partly silicified, showing growth rings. In upper coal group about 50 feet above level of H-22. A short distance southeast of H-22. About 1/2 mile south-southwest of Mount Glossopteris.

H-25 Shale, black, platy, hard, with sand grains; *Glossopteris* leaves and platyspermic seeds on bedding surfaces. Nearly same stratigraphic level and about 50 yds. down slope from H-22, elevation about 9600 feet, about 1/2 mile southwest of Mount Glossopteris.

(Samples H-19 and H-21 through H-25, from the open face of lower summit southwest of Mount Glossopteris; beds dipping about 5 degrees south-southeast.)

PRESERVATION OF PLANT MATERIAL

Preparation of fossil plant material for detailed examination depends, first of all, upon preservation of the fossil, and, next, upon differences in chemical characteristics of fossils and matrix. This is equally true of megafossils and microfossils, whether the microfossils are derived from coal or from mineral sediments. Preparation depends on exposing significant features of fossils by removing, dissolving, or dispersing the enclosing rock matrix. Plant microfossils must be isolated from the matrix in order to observe their morphologic features microscopically at high magnification.

Coal consists dominantly of plant materials in three rather distinctly different modes of preservation (Schopf, 1948). The same kinds of coalified materials are present in carbonaceous sediments. In part, the different modes of preservation are conditioned by differences in the initial composition of plant material, but not entirely so. No complete answer is yet available to explain satisfactorily all the preservational differences originating in different substances synthesized by plants, because the same plant products can be shown to be represented in each of the different modes of preservation which characterize coal and are not directly related to the tissues of the plants. Modes of preservation evidently depend on the microenvironments of accumulation in which differences of a critical nature can develop within a distance of a few millimeters. When differences of minute variation are so important, it is difficult to determine the environmental causes exactly, and any generalization is inadequate which does not account for microvariation in the preservational environment. For present purposes it is sufficient to recongnize that different modes of carbonaceous preservation exist and largely determine the success of microfossil preparation.

Petrified plant material which results essentially from infiltration and permeation of plant tissue by saturated or supersaturated mineral solutions, leaving a complete protective deposit of microcrystalline mineral matter, is least difficult to explain in general terms. The plant material is little altered by this type of mineralization and the process seems directly analogous to the paraffin-embedding technique generally used in plant histology. This mode of preservation is likely to be most satisfactory botanically but the physical chemistry of mineralization probably is much more complex than the crude analogy with paraffin embedding would indicate.

Compression types of fossil plant material, including plant microfossils, are coalified. Coaly material, in general, is noted for its insolubility in reagents. Solution involves molecular dispersion in a solvent and is most useful as an initial means of segregation without destruction of unknown compounds for identification in analytical chemistry. Very little material constituting coal is really soluble. Even lowest rank coal that appears to be soluble in alkaline reagents does not form a true molecular solution. The dispersion effected is colloidal rather than molecular and the colloidal particles in such a dispersion probably are both complex in their molecular composition, and altered with respect to their in situ condition in the coal. They have been called regenerated humic acids because they show analogy with the complex humic acids derived from humus in the soil, but there is no reason to believe that these analogies have genetic significance. Nevertheless, ability to form a colloidal dispersion after chemical treatment differs according to mode of plant tissue preservation in coal and is one of the differential properties useful in segregation of plant microfossils.

Plant material preserved as vitrain or previtrain is most easily dispersed colloidally but in high rank coal it, too, becomes very resistant. Waxy-resinous, and chitinous materials resist dispersion, owing largely to their inherent initial differences in composition. When these substances are incorporated in coal, their initial composition resists change and the changes that occur as a result of incoalation merely tend to increase further resistance to dispersion. Consequently, the waxy-resinous-chitinous materials readily preserve morphologic features and anatomical characteristics that are botanically identifiable and which make them most suited for paleontologic use as microfossils. The problem of separating these materials from the vitrain usually is not difficult if the coal is not high rank. However, coal that has been naturally devolatilized to the stage of low-volatile bituminous or higher rank contains microfossils that are altered chemically. Moreover, vitrain in high rank coal is nearly as resistant to dispersion as the microfossils themselves. Microfossils are especially difficult to prepare from high rank coals because the chemical properties responsible for differential dispersal and segregation of fossils and vitrain in lower ranks of coal have been reduced, and the common techniques used for fossil isolation are likely to fail.

Plant material also is preserved in coal as fusain. Apparently any kind of plant substance can be fusinized and preserved in a charcoal like condition that preserves original morphologic features of plant tissue with amazing fidelity but lacks chemical resemblance to the original material. Fusinized materials generally have a very high carbon content and are nearly opaque to transmitted light. They may be bleached to some extent by use of strong reagents, but their opacity, in general, renders microscopical examination more difficult. Fusinized tissue fragments are the most persistent types of plant fossil materials because they are the least dispersable by chemical action and most resistant to morphologic alteration; they form early in the coalification sequence and are widely distributed in sedimentary deposits other than coal. Initial chemical alteration results in fusinized tissues becoming very hard and brittle so they tend to break into fragments and particles suitable for sedimentary distribution. Tiny cellular fragments of fusinized tissue probably are the most peristent and widespread of all the various types of plant microfossils. It is unfortunate that cell wall structures are not more diagnostic of plant relationship. Nevertheless, some botanical information can be obtained from study of tiny fusinized fragments of fossil plants.

Coal of the central range of the Horlick Mountains apparently has all be altered to relatively high rank as a result of regional metamorphism. All the coalified plant compressions and microfossils that have not been protected by petrifaction have been correspondingly affected. Semianthracite is a high rank coal in which most of the waxy-resinous-chitinous materials have been partially devolatilized so that their chemical characteristics approach the vitrinized portion. The vitrinized part of semianthracitic coal is highly resistant to colloidal dispersal, following even a very strong chemical treatment. The contrasting chemistry of the respective plant materials incorporated and vitrinized in lower ranks of coal, upon which preparatory meceration and the separation of well preserved microfossils depend, is greatly reduced in semianthracite. Up to now, it has not been possible, therefore, to obtain satisfactory microfossil assemblages directly from coal of the Horlick Mountains.

PLANT MICROFOSSILS

Preparation of microfossils from carbonaceous sediments depends much more upon the differential solution characteristics of the mineral and carbonaceous material than in preparation of microfossils from coal. Silicate minerals are soluble in hydrofluoric acid; carbonates in hydrochloric, acetic, or formic acid. None of these has much effect on carbonaceous substances. Greater success has been achieved in separation of pollen grains from the Horlick Mountains' sediments than from coal. Disaggregation of the rock leaves the carbonaceous microfossils sufficiently exposed so that differential oxidation may be used to "clean up" features for microscopic study. Even so, only a few of the fossils are very well preserved; probably these few were protected by a crystalline mineral matrix from maximum metamorphic devolatilization. Most of the spores and pollen grains are strongly altered chemically. They often are only recognizable from skeletonized morphologic remains, corroded by oxidation reagents used in preparation. Most of them do not show all the features needed for biometric characterization or taxonomic comparison, but enough have been found to indicate the general nature of the assemblages.

It is entirely possible that different methods of preparation can be applied which will be more successful for disclosing the characteristics of these fossils. For this reason, it seems best at the present time to refrain from detailed taxonomic treatment.

Terms used in description of some of these types of spores are illustrated in Fig. 2.

Procedure

Carbonaceous samples were trimmed by dry bonded abrasive cut-off saw to provide representative slices three or four grams in weight. The slices were split by hand into flakes less than a millimeter thick and

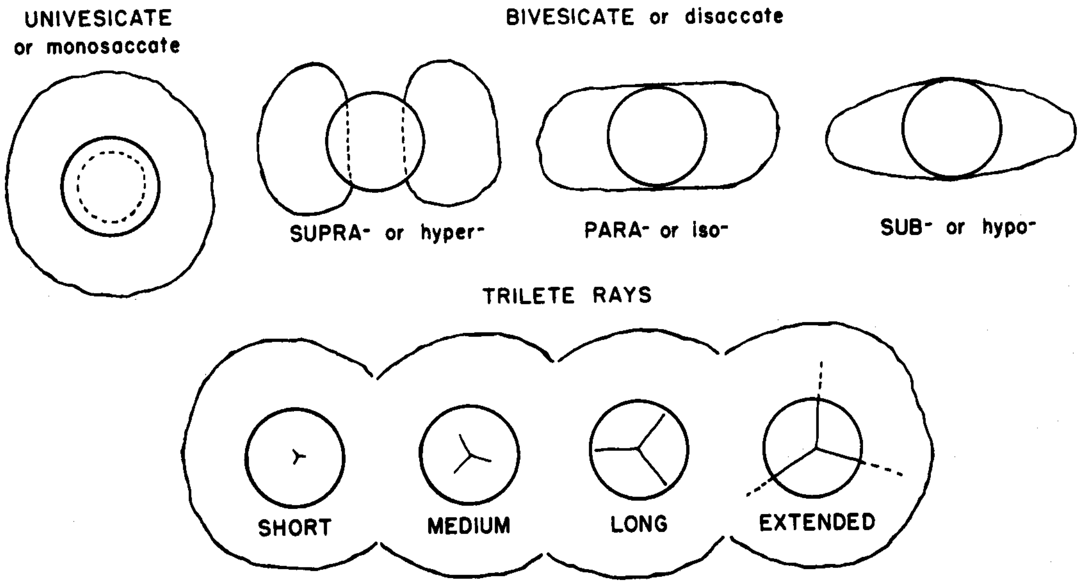

Fig. 2. Descriptive terms for spores

disaggregated by dissolving silicate minerals in hot hydrofluoric acid. Disaggregation was carried out using Teflon (tetrafluoroethylene) beakers on a hot plate in a fume hood with positive ventilation. Recalcitrant samples required over 30 hours treatment. The hydrofluoric acid was removed by diluting with water and decanting after a period of settling. Final traces of acid were removed by adding more water and using a centrifuge to hasten settling of the residue.

Some of the disaggregated residues were examined under the stereoscopic microscope when all hydrofluoric acid had been removed. In general, results at this stage were inconsequential and the appearance of all types of fragmental fossils which were present were greatly improved by subsequent oxidation treatment.

Moist disaggregated residues were treated with concentrated nitric acid to which a small amount of potassium chlorate (granulated crystal) was added. After stirring and a few minutes observation to safeguard against the possibility of boiling reaction (these samples proved to have little pyrite and violent reaction was unusual), the sample tubes were placed in a beaker of hot water on the hot plate to hasten their oxidation. About the same result could be obtained in one or two hours by this method as by several days treatment at room temperature in the same oxidizing medium.

The oxidizing agents were removed from the residues by dilution in water and centrifuging. The most readily oxidized material was dispersed as a humic solution by treatment with dilute potassium hydroxide. After humic matter has been thoroughly washed out, the residues were partially dehydrated in alcohol and transferred to butyl cellosolve in watch dishes and observed. Larger fossils and any coarse incidental fragments were removed, fossil fragments were placed directly on slides, and any remaining rock granules were discarded. Ultrafine nonfossil material that remained was largely eliminated by decanting from dishes after the coarser fossil material had settled. Some selected specimens usually were transferred to slides for mounting in balsam directly. Most of the material was stained with safranin and cover slip slides prepared according to procedure described elsewhere (Schopf, 1960). The types of microfossils found in the samples examined are described and discussed on the following pages.

TYPES OF MICROFOSSILS

Spore A. Accinctisporites (?) sp.
Plate 1, Figures 1, 4, 8, 11a, 11b, 13 (?);
Plate 2, Figures 9, 13 (?)

Description.--Univesicate, subcircular or elliptical, ranging from 70 to 110 microns (commonly 85-100μ) in diameter, central body generally eroded, duplicate bladder margin 10 to 20 microns wide, infrareticulation irregular with lumens 2-4 microns across.

Occurrence.--Coal measures, central range of the Horlick Mountains. Sample H-22 (Maceration 933, slides 1, 13); H-22 Maceration 922, slide 13.

Discussion.--This form resembles, but is smaller than, *Accincti-sporites exundatus* and *A. nexus* described by Leschik (1959) from the Karroo sandstone of Norronaub (Dwyka age) in West Africa. Owing to metamorphic alteration of the Antarctic material, a close comparison with other species is not possible. It is possible that haptotypic features might be present and comparable with the spores usually assigned to *Nuskoisporites* or to other groups. Although smaller, spore A resembles spores 30 to 35 of Virkki (1946), described from the Lower Gondwana deposits of India and Australia.

Spore B. *Accinctisporites* (?) sp.
Plate 1, Figures 2, 9, 10 (?), 12; Plate 2, Figures 8, 15;
Plate 3, Figures 2-6; Plate 4, Figure 6 (?)

Description.--Univesicate, subcircular or elliptical, ranging from about 110 to possibly 160 microns, mostly 115-140 microns, in diameter, central body dark or often irregularly eroded, duplicate marginal bladder zone often is less definite than in spore A, ranging perhaps from 15 to 40 microns in width, infrareticulation slightly coarser.

Occurrence.--Coal measures, central range of the Horlick Mountains. Sample H-22 (Maceration 933, slide 1, 13); H-10-1/2 (Maceration 946, slide 2).

Spore C.
Plate 1, Figures 5, 6; Plate 2, Figure 14; Plate 4, Figure 15 (?)

Description.--Univesicate (?), elliptical, about 65 x 70-80 microns in diameter, central body (?) generally eroded, duplicate marginal bladder zone possibly about 12 or 14 microns wide but often indefinite or irregular, pattern of reticulation irregular, with lumens of 3 or 4 microns.

Occurrence.--Coal measures, central range of the Horlick Mountains. Samples H-22 (Maceration 933, slides 13, 1); H-10 (Maceration 929, slides 9, 5).

Spore D. *Accinctisporites* (?) sp.
Plate 1, Figures 3, 7; Plate 4, Figure 8 (?)

Description.--Univesicate, irregularly subcircular, usually 90-100 microns in diameter, central body elliptical, usually 50 x 65 or 70 microns in diameter, dark, with lunate folds. Bladder commonly folded, probably disengaged distally, membrane equatorially thickened with infrareticuate muri thicker or intergrown forming a band 8 or 10 microns across; lumens elsewhere generally 3 to 6 microns in diameter.

Occurrence.--Coal measures, central range of the Horlick Mountains. Sample H-10 (Maceration 929, slides 5, 9).

Spore E.
Plate 2, Figures 1, 2, 3, 4, 10 (?), 11, 16 (?)

Description.--Parabivesicate, elliptical, commonly about 105 x 65 microns overall, but varying from 100 to 120 microns in length and 35 to 80 microns in breadth. Bladder membranes seem essentially continuous but divided; individual sacci definite, proportioned about 45 x 65 microns, leaving a narrow sulcus between on the central body. Central body circular or elliptical but margins are hard to define. The contour of the body is suggested by the bladders. Bladder membranes infrareticulate, lumens 2-5 microns in diameter. Body ornamentation obscure, proximal cap may be lacking, no haptotypic vestige has been observed.

Occurrence.--Coal measures, central range of the Horlick Mountains. Sample H-10 (Maceration 929, slide 9); H-22 (Maceration 933, slides 1, 14).

Spore F.
Plate 2, Figures 6, 7; Plate 3, Figure 15 (?)

Description.--Parabivesicate, elliptical, commonly 65 x 80 microns overall, but varying from possibly 50 to 80 microns in length and 50 to 65 microns in breadth. Bladder membranes essentially continuous but divided, with a proportionately broader sulcus than spore E; central body is similarly obscure. Individual sacci 30 to 40 microns long, shorter than in spore E with similar endoreticulum.

Occurrence.--Coal measures, central range of the Horlick Mountains. Samples H-22 (Maceration 933, slides 1, 13); H-18 (Maceration 930, slide 3).

Spore G. Striatites (?) sp.
Plate 2, Figures 5, 12a, 12b

Description.--Parabivesicate, generally somewhat reniform owing to inclination of the sacci, 95 x 45 microns overall. Bladder membranes continuous equatorially with characteristic endoreticulum, proximal caps usually distinguished by a few transverse cristate ridges, coarsely granulose but apparently not otherwise thickened, sulcus shallow. Central body obscure, apparently broadly ovate.

Occurrence.--Coal measures, central range of the Horlick Mountains. Sample H-10 (Maceration 929, slide 9).

Discussion.--Although the transverse cristate ridges resemble the longitudinal ridges described for species assigned to Striatites Pant (1955), they appear to be less numerous than in other species. There is no suggestion of a laesura or proximal suture line like that of Lueckisporites virkkiae Potonie and Klaus (1954).

Of the microfossils described here, this form, now tentatively assigned to Striatites, is most similar to the pollen of Pityosporites antarcticus Seward, originally described from the Terra Nova Bay area of South Victoria Land. Although Striatites differs in important respects from Pityosporites, a few years ago such specimens would have been assigned unquestionably to that genus. Part of this difficulty was for want of very critical consideration of the morphologic features of the pollen. Disaccate pollen is now known to be much more diversified and diagnostic than was previously considered. In this connection, some of the history of Pityosporites antarcticus Seward (1914), the first plant microfossil to be described from the Antarctic continent, may be of interest.

Seward originally observed the Pityosporites pollen as a silicified grain caught in a crack of wood of Antarcticoxylon priestleyi, which was based on an erratic specimen from morainal debris on the Priestley Glacier of the Terra Nova Bay area. He described it as coniferous pollen of a modern type. Later, when Walton (1923, 1925) reexamined the wood of Antarcticoxylon priestleyi and emphasized the possibility of tertiary growth in the wood, the presence of a pollen grain in an open crack seemed anomalous. Walton transferred the woody specimens to Rhexoxylon, admitting that the small pith area was not exactly comparable and suggesting that Seward's pollen grain was not a pollen grain at all but simply a shrunken, displaced, sclerotic cell from the pith. Edwards (1928) agreed with Walton in regarding the example as "merely a shrivelled pith cell."

Thomas later rephotographed the pollen grain and Seward republished this as an illustration in a paper (Seward, 1933) in which he accepted assignment of the wood to Rhexoxylon, but did not recant in his view that he had, indeed, found an example of fossil conifer pollen trapped in a crack of the silicified wood. He suggested that the grain might belong to the podocarps rather than Abietineae. Recently, Cranwell (1959) has discussed the affinity of these examples of Pityosporites pollen which she considers in relation to pteridosperms. Even more recently, Manum (1960) reexamined the questioned pollen grain which, as the holotype of the type species of Pitysporites, has assumed increasing importance for taxonomy based on fossil pollen grains. He has published a new detailed description of the pollen grain, which he now shows is adequately preserved for diagnosis, and illustrates by a series of photomicrographs at different focal levels. Manum, like Seward, emphasizes the modern aspect of the fossil. He is not inclined to credit relationship to pteridosperms, and regards it podocarp affinity as more probable. There is no longer any reason for confusion of Striatites with Pityosporites and the former genus appears to have an older connotation. There can be no further doubt regarding the identity of the pollen and the validity of Pityosporites antarcticus as a taxon of plants.

Spore H.
Plate 3, Figure 1

Description.--Probably supratrivesicate, possibly corresponding generically with the form described by Leschik (1956, p. 130) from the Upper Zechstein near Fulda, in east central Hessen, as Inversisporites pectinatus. Leschik's illustration of this form is not clear. It also resembles spore 96 of Virkki (1946, p. 136) from Warchha, below the Middle Productus limestone in the Salt Range, Pakistan. According to this interpretation, the three expanded bladders are about 50 microns in diameter; the central body a little smaller. No haptotypic structure is visible. Preservation is not very good and this is the only fairly complete example that has been observed.

It also is possible this specimen represents a partially separated tetrad of simple spores, corresponding to the spore type 23 described by Virkki (1946). However, such an interpretation seems less likely because the central body does not seem to be as reticulated as the bladders. Some of the reticular appearance may be caused by maceration but it is so pronounced that I believe it represents an endoreticulum.

Occurrence.--Central range of the Horlick Mountains. Sample H-22 (Maceration 933, slide 1).

Spore I.
Plate 3, Figure 8

Description.--Parabivesicate, 50 x 33 microns. A single specimen, generally similar to spore E but smaller, was observed.

Occurrence.--Central range of the Horlick Mountains. Sample H-22 (Maceration 933, slide 13).

Spore K.
Plate 3, Figure 7; Plate 4, Figure 14 (?)

Description.--Univesicate, similar to spore D but smaller, bladder subtriangular, central body definitely triangular. Two specimens which may be conspecific were observed.

Occurrence.--Central range of the Horlick Mountains. Sample H-22 (Maceration 933, slide 13).

Spore L.
Plate 3, Figure 10

Description.--Spore simple, ovate, about 20 microns in greatest diameter, wall relatively thin but dense, haptotypic marking obscure.

Occurrence.--Central range of the Horlick Mountains. Sample H-18 (Maceration 930, slide 6).

Spore M.
Plate 3, Figure 12

Description.--Spore simple, subcircular, nearly 30 microns in diameter, wall relatively thick (5μ), dense, haptotypic marking obscure.

Occurrence.--Central range of the Horlick Mountains. Sample H-18 (Maceration 930, slide 6).

Spore N.
Plate 3, Figure 13; Plate 4, Figures 7 (?), 12 (?)

Description.--Spore simple, subtriangular, about 45 microns in diameter, probably trilete (aperture may be small), equatorial thickening moderate, surface badly corroded, may be apiculate or rugose. The specimen in Plate 4, Figure 7, doubtfully referred to this form, appears definitely reticulate.

Occurrence.--Central range of the Horlick Mountains. Sample H-18 (Maceration 930, slide 6); H-10 (Maceration 929, slides 8, 4).

Spore O.
Plate 3, Figure 14; Plate 4, Figure 2

Description.--Spore simple, oblate subtriangular, 55-60 microns in diameter, trilete, rays extending nearly to the margins, surface coarsely granulose with rounded granules up to 2 microns in diameter, spore coat about 3 microns thick.

Occurrence.--Central range of the Horlick Mountains. Sample H-18 (Maceration 930, slide 7); H-10-1/2 (Maceration 946, slides 1, 4).

Spore P.
Plate 3, Figure 16

Description.--Spore simple, elliptical (essentially circular ?), trilete ?, wall uniformly reticulate. Only a reticular skeleton remains after maceration.

Occurrence.--Central range of the Horlick Mountains. Sample H-22 (Maceration 933, slide 13).

Spore R.
Plate 4, Figure 13

Description.--Spore simple, triangular, about 40 microns in greatest diameter, trilete, rays extended nearly to margins, wall smooth, relatively thin (about 1μ), but dense.

Occurrence.--Central range of the Horlick Mountains. Sample H-10 (Maceration 929, slide 5).

Spore S.
Plate 4, Figures 1, 4 (?)

Description.--Spore simple, broadly subtriangular, 50-60 microns in greatest diameter, probably trilete but rays not observable, surface with conate spines or spinules 2 or 3 microns in basal diameter and 2-4 microns long. Wall possibly 1-3 microns thick at the equator.

Occurrence.--Central range of the Horlick Mountains. Sample H-10-1/2 (Maceration 946, slides 5, 3).

Spore T.
Plate 4, Figure 5

Description.--Sporelike body about 65 microns in diameter, texture irregularly reticulate, "fluffy," lacking definitive marking.

Occurrence.--Central range of the Horlick Mountains. Sample H-10-1/2 (Maceration 946, slide 2).

Discussion.--Incidental particles of this type might be meaningless objects or artifacts. However, these bodies possess substance and can be manipulated; they are not uncommon and they have a fairly consistent size and texture. They probably are poorly preserved fossils but they may not be spores despite sporelike appearance.

Spore U.
Plate 4, Figure 3

Description.--Spore simple, subtriangular, about 60 microns in diameter, trilete, rays extended, surface smooth, wall relatively thin (about 1μ).

Occurrence.--Central range of the Horlick Mountains. Sample H-10-1/2 (Maceration 946, slide 1).

Spore W.
Plate 4, Figure 9

Description.--Sporelike body, ovate, about 55 x 45 microns, very dense, surface rugose with suggestion of sporelike wall about 2 microns thick.

Occurrence.--Central range of the Horlick Mountains. Sample H-10 (Maceration 929, slide 5).

OTHER FORMS

The example illustrated in Plate 4, Figure 10, found in the maceration preparations of Sample H-8, is very sporelike, highly translucent and yellow. It is ovoid, about 30 x 45 microns in diameter, and resembles *Tasmanites*. It is unique in the material studied and may well represent a poorly preserved specimen referable to *Tasmanites*, contaminant in the Antarctic macerations.

The specimen shown in Plate 3, Figure 11, from Sample H-22, may represent a simple type of reticulate spore about 33 microns in diameter, but it is too poorly preserved for description.

The hexagonal perforate structure about 20 microns in diameter, wall 5 microns thick, shown in Plate 3, Figure 9, from Sample H-18, is distinctive, ambiguous, and unique.

The constricted attenuate spindle shown in Plate 4, Figure 11, from Sample H-10, may represent the corroded remains of a resinous cell filling. A few other similar examples have been observed.

FUSAIN FRAGMENTS

Fusain fragments are the dominant microfossils in maceration residues prepared from this Antarctic material. Some are simply ambiguous fragments of cell walls without definable biocharacters; others show details of pitting and ray structure which may be of value. Some of this fusinized material is illustrated on Plate 5. Figures 1, 3, 5, and 6, showing various types of pitting, are all from Maceration 928 of Sample H-8, and Figs. 2 and 7 are from Maceration 933 of Sample H-22. Figures 4 and 8 are from Maceration 929 of Sample H-10. Figures 9a and b show a fragment of a larger plant axis with checking characteristic of the fusinized mode of preservation. Shrinkage incident to fusinization produces an effect similar to fire charring.

It is not surprising that several authors (Seward, 1914; Debenham, 1921; and others) have suggested that such "carbonization"* might be caused by heat arising from dolerite intrusions, but this is impossible. Debenham (1921, p. 107) cites the "large masses of charred stems" of the Granite Harbor and Terra Nova Bay areas as evidence of "considerable thermal action." He, apparently, had no doubt that the charring was due to intrusion of dolerite. He mentions (p. 108) the "charred fragments of stems" in hard, bright coal erratics in the central moraine of the Mackay Glacier as having been subjected to high temperature. On a later page (p. 111), the ubiquitous fragments of stem from moraines of the Priestley Glacier are said to be "in most cases charred by heat."

It seems very likely, of course, that at one time or another the fossil stems have been subjected to heat of igneous intrusives but, regardless of this, the "charred fragments" that are reported seem to represent only a normal occurrence of fusain and fusinized plant remains. Unfortunately, fusinized stem fragments will not provide evidence of thermal history. The conclusion must be that the fusinized ("charred") material was originally introduced in that form into the deposit long prior to igneous intrusion. Otherwise, these plant remains would also have formed anthracitic, devolatilized, hard, bright coal. Debenham seems to have realized something of this relationship (p. 112), but he ignores it in his zeal to invoke igneous heating. However, coalification is an irreversible process and once a plant fragment has been compressed and vitrinized or otherwise coalified, it cannot regain a charcoal texture, no matter how much it is heated. Natural coke may form from igneous intrusion of bituminous coal beds, but the vesicular structure of coke differs materially from the plant tissue texture of fusain or of charcoal. Fusain is not formed by igneous intrusion and there is nothing in any of these occurrences to indicate an origin that differs from that of the common fusain occurrences in many types of carbonaceous sediments and in coal beds all over the world.

Figure 1, Plate 5, illustrates a type of scalariform pitting which resembles the scalariform tissues illustrated by Seward in leaf traces and pith area of one of the stems from Priestley Glacier, Terra Nova Bay area, which was identified as Antarcticoxylon priestleyi. I have observed it, also, in macerated washings from coalified compressions of Glossopteris leaves, probably derived from veinlets. Ghosh and Sen (1948, Plate 7, Fig. 82) have illustrated somewhat similar pitting in connection with tracheids bearing bordered pits obtained from the Raniganj coal field in Bengal, India, and Kräusel and Dolianiti (1958) have illustrated it in Permian wood from Brazil. Scalariform pitting has been observed infrequently in the Antarctic fusain, but it should not be taken as evidence of restricted botanical affinity. Fusain with scalariform pitting might be derived from primary xylem commonly found in many vascular plants.

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* The term "carbonization," frequently misused by geologists, properly applies to the process whereby coal is heated and devolatilized with an alteration of physical structure, in an oxygen-deficient atmosphere. Natural carbonization (coking) may accompany igneous intrusion of coal beds.

Uniseriate and occasional multiseriate bordered pits are present on other fusain fragments of the same macerations (Plate 5, Figs. 2, 3, 6, 7) from the central range of the Horlick Mountains. Bars of Sanio have not yet been observed. Figure 5, Plate 5, illustrates a wood ray, probably multiseriate and fusiform, at least 10 cells high. The radial walls of ray cells seem to have large simple pits. All these features can be found in secondary wood identified as Dadoxylon and it is, also, present in Antarcticoxylon discussed in a later section of this report. The prevalence of fusain showing characteristics of secondary xylem in many maceration residues from the central range of the Horlick Mountains suggests the prevalence in land and swamp areas of an abundant, not necessarily diversified, gymnosperm flora.

FOSSIL WOOD

Notes on Preparation

After cleaning suitable specimens and obtaining megascopic photographs, specimens of silicified wood were sliced to expose their principal planes for anatomical examination. A few very dark specimens were lightly etched prior to cutting to bleach the exterior and clarify orientation. Cellulose acetate peels were obtained after hydrofluoric etching by the method described by Joy, Willis, and Lacey (1956). In many instances, the structure was most evident while peels were still in place. Favorable areas of peels were mounted on slides in balsam for detailed study by transmitted light.

Thin sections were prepared by the usual methods from several specimens to illustrate modes of mineralization and demonstrate more clearly features not disclosed by peels. Since the principles of preparing peel sections and thin sections are completely different, the two procedures complement one another and provide information that neither procedure could supply alone. In general, however, botanical features are most easily photographed from sections prepared by the peel technique. Thin sections show best the features related to mineralization.

The woody material from collection H-15 was friable and required an entirely different method of preparation. Pieces cut from the specimen were set overnight in hot melted carnauba wax. After cooling, it was possible to prepare polished surface sections according to the principal anatomical planes and study microscopic features. A discussion of selected specimens from the various woody collections is given below.

ANTARCTICOXYLON sp., cf. A. PRIESTLEYI Seward
Plate 6, Figures 1-6; Plate 7, Figures 1-7b;
Text Figures 3a, b

To a considerable degree, recognition of Triassic age rocks in the horst area of Antarctica has been dependent on the identification of a fossil log found erratic on Priestley Glacier, Terra Nova Bay region, with the South African genus Rhexoxylon (Walton, 1923; 1925; 1956). Recently, Kräusel (1956) has questioned the redetermination made by Walton. The wood from the sedimentary section of Mount Glossopteris strongly resembles the wood Seward identified from Priestley Glacier and the generic determination is made largely for this reason. Information bearing on identification with Rhexoxylon has been searched for. Although the new Horlick material is not well preserved, it evidently is better preserved in a few details than that Seward described from Priestley Glacier. Unfortunately, the new material does not seem to provide any more critical information as to its affinity. The wood might also be assigned to Dadoxylon, as are many of the other specimens showing features of gymnospermous secondary wood with growth rings from Gondwana terrains. Some of the other genera described by Krausel and Range (1928) and by Kräusel and Dolianiti (1958) also are not excluded. None of the new material shows clear evidence of features of anomalous growth which should be demonstrated for positive assignment to the genus Rhexoxylon. In general features, characteristics common to gymnospermous woody axes frequently found in the Late Paleozoic and Early Mesozoic deposits of Gondwana areas are represented. The wood shows no characters or associations with other plants that suggest Triassic rather than Permian age.

One stem segment about 15 cm long, which was broken from a longer piece horizontally embedded in coal measures deposits on Mount Glossopteris, is the principal source of information. Other more fragmentary specimens are discussed on a later page. Some of these pieces were lying loose on the surface but, according to Long (personal communication, April 1961), there is no doubt as to their local origin from the central range of the Horlick Mountains coal measures section now exposed.

Description

The woody axis principally studied is about 9 x 13 cm in diameter, silicified, with two or three radiating fissures and irregular zonal banding. A thin, coaly layer is attached at a few places on the outside. The weathered end of this specimen is shown on Plate 6, Fig. 3, after etching in hydrofluoric acid to make its structure more evident. The pith area is small in this specimen and is more poorly preserved than in Seward's type specimen of Antarcticoxylon priestleyi. One principal longitudinal split is developed in the Horlick stem in contrast to two or three fissures in the Priestley Glacier specimen. Whereas fragments of displaced wood, some of which have been interpreted as anomalous, together with a foreign pollen grain (see p. 14-15; p. 23 and 25), were found in the longitudinal splits of the stem in Antarcticoxylon priestleyi, these were not observed in the Horlick specimen. There is nothing to indicate that the longitudinal fissure was more than an incidental fracture in the wood of a fast-growing softwood stem. The principal split probably developed from exposure before mineralization, subsequent to life of the plant. Other fissures may have developed later.

Study of HF-etched surfaces and peeled sections prepared after etching showed that tissue preservation was poor in all but one area of this specimen (marked "A" in Fig. 3, Plate 6). This area is nearly all derived from a single growth ring although it is opposed to at least three of the conspicuous concentric zones of banding. Figure 2, Plate 6, reproduced at 100 x, is a composite made up of several matching photographs that extend across about half the thickness of the single growth ring. The narrow zone of late wood, 8 to 10 cells thick, is shown near the top of the figure, just below larger cells of the next succeeding annual ring. A thickness of about 150 cells of early wood of the thick growth ring are shown in Fig. 2. The total thickness of the ring, extending into the poorly preserved area beyond the bottom of the figure, may have included nearly that many cells more. Only one true growth ring termination is shown and it crosses the better preserved area somewhat diagonally. Beyond this zone it is impossible to be sure where a growth ring begins or ends.

The zigzag compression lines within the wood have no relation to growth rings, although they tend to be parallel to them. Similar preservation appears in Seward's specimen from Priestley Glacier. The only point of striking contrast between this Horlick Mountains' specimen and that described by Seward (1914, p. 18) from Priestley Glacier (Terra Nova Bay area) is that he apparently interpreted the zigzag compression lines as growth rings, since he records the growth rings as from "less than one mm to more than two mm in breadth."

The one growth ring of the Horlick specimen has only been compressed about one-third and it will serve as a basis for estimating the normal thickness of annual growth. It must have been between 6 and 8 mm thick. If we consider the total radius of the specimen is about 60 mm and probably has been contracted about one-half, the whole stem was derived as a result of growth over a period of 15 to 20 years. It thus shows remarkably rapid growth and is quite comparable in this respect with <u>Dadoxylon</u> <u>bengalense</u> Holden (1917).

About 30 compression bands can be counted in the Horlick specimen described, but they show a considerable irregularity in detail and probably nowhere do they represent true growth rings. I am inclined to attribute their inception to general collapse as a result of a rather uniform depletion of cellulose from the wood, as shown by other specimens discussed later, rather than as a direct result of overburden pressure. The bands are just about as prominent on the flanks as they are on the top and bottom of the specimen. The collapsed lignin "skeleton" of the wood was rather solidly mineralized, but there can be no doubt that a thick cellulosic layer of the secondary cell walls has been removed prior to mineralization of the tissues in this stem. Similar occurrences have been described and investigated in detail by Barghoorn (1949a, 1949b, 1952). Other specimens of petrified wood from the central range of the Horlick Mountains, partially preserved by limonite rather than by siliceous minerals, show the full original thickness of cell walls and are illustrated in a later section of this report.

Figures 5 and 6, Plate 6, illustrate transverse sections across the narrow late wood zone. The large celled early wood, which formed subsequent to the annual winter dormancy, shows somewhat thicker lignin residues than the late wood. These figures also show the range of variation in spacing of wood rays. In Fig. 6, the rays are virtually alternate with single files of tracheids; in Fig. 5, an interval of as many as five tracheid files appears to intervene.

Further information about ray structure and occurrence is shown by the tangential section in Fig. 4, Plate 6, and in text Figs. 3a and 3b. The rays are abundant, fusiform, usually uniserate and less than eight cells high. No leaf traces were present in the relatively small "best preserved" sector of this stem, but so far as is known larger, multiseriate rays could have been present adjacent to leaf traces.

Details of pitting on radial walls are illustrated on Plate 7. The bordered pits of tracheids are either uniseriate or biseriate (Fig. 3). If biseriate, they are more commonly in alternate arrangement though some may be nearly opposed (Figs. 4, 6). The pits show considerable variety of spacing, occasionally being crowded (Fig. 7), commonly relatively isolated (Fig. 6). Bars of Sanio are lacking. Apparently one to four simple ovate pits may occupy a single pit field of the ray cells, but commonly there are two (Figs. 1 and 2). All illustrations on Plate 7 are at 500 x with the exception of Fig. 7b, which is magnified 1000 times.

The wall texture, well shown in radial sections such as in Plate 7, Fig. 7b, is of interest. At lower magnification and in transverse section (see figures on Plate 6), the reticular irregularity is scarcely noticed. Longitudinal sections, however, show the cell walls have all been extensively corroded. The portions remaining here probably are chiefly altered lignin residues. Only occasionally, as in Plate 7, Fig. 6, are the circular pit margins preserved which may still include some altered cellulosic material. Similar preservation occurs in the Antarcticoxylon specimen Seward (1914) described from Priestley Glacier in the Terra Nova Bay area, and an amazingly similar type of preservation is shown by a South African specimen from Catherine's Post, Dordrecht, Cape Province (Walton 1925, pl. 3 Fig. 14). I have not noticed exactly similar types of reticulate preservation of the lignin skeleton in silicified wood from the Northern Hemisphere.

Apparently this is the type of reticular structure, which simulates the infrareticulum of coniferous pollen, that led Walton to suggest (1925, p. 11) that the pollen grain of Pityosporites antarcticus

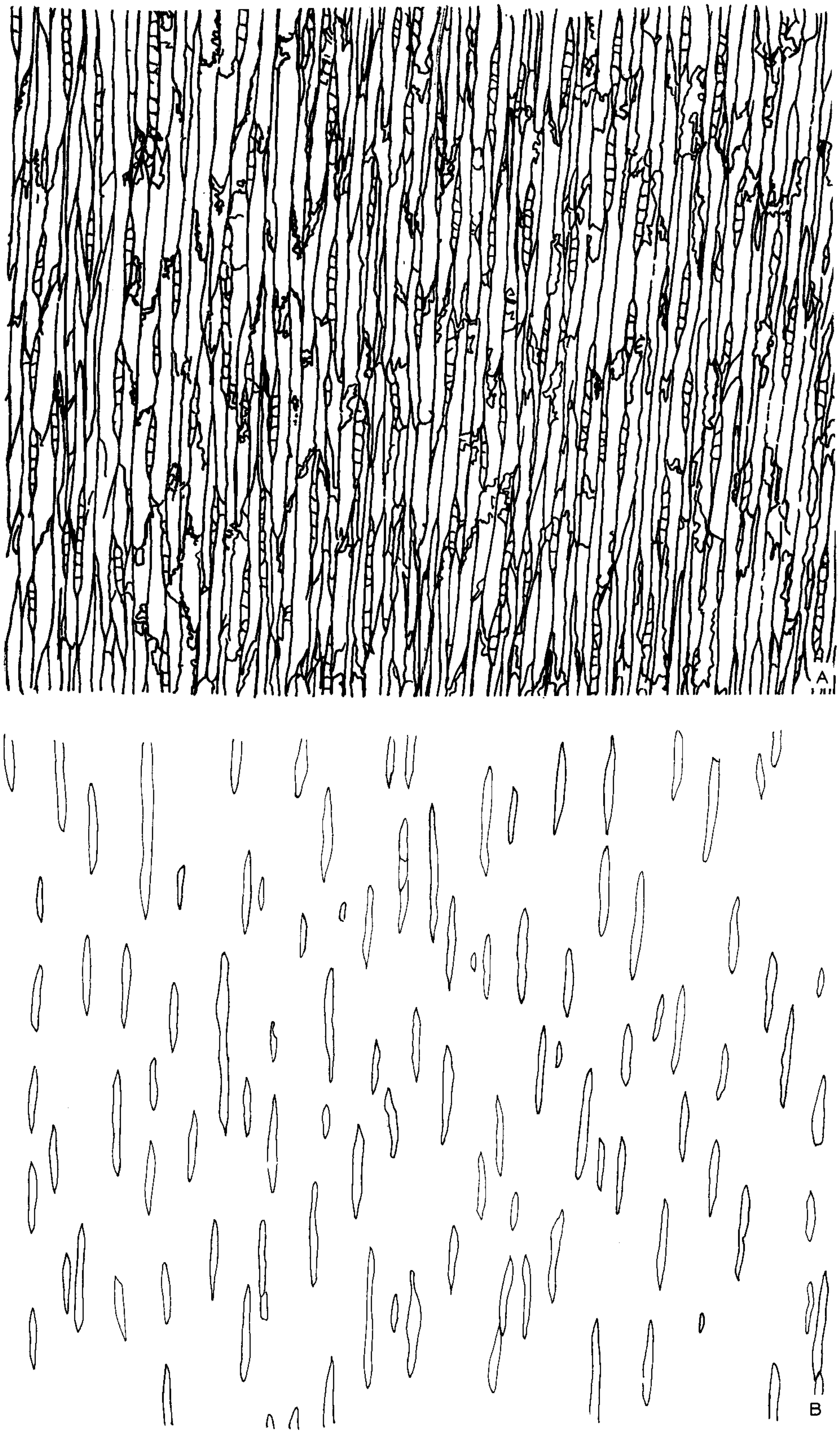

Fig. 3 A, Tangential section of secondary wood from locality H-21
B, Tracing showing woodrays in A

described by Seward (1914) might represent a crushed or irregularly shaped stone cell, actually indigenous and only slightly displaced, within the woody specimen from Priestley Glacier. Seward (1933) later commented on Walton's suggestion and appears to have rejected it. Recently, Manum (1960) has published additional photographs of Seward's pollen grain that show ample details for characterization. The diversified material included in this report provides a further basis for comparison of indifferently preserved, originally reticulate membranes of gymnospermous pollen, and the reticulation induced by degradation of the lignin skeleton in secondary wood prior to mineralization. The original chemical composition of spore or pollen coats and ligno-cellulosic tissue was very different, and the fact that a difference in interpretation can arise between qualified observers as to the nature of such diverse fossil materials is in itself a commentary about the alteration the substances have undergone in this terrain during burial, mineral emplacement and, at least in the case of isolated microfossils in shale, during subsequent loading and metamorphism.

Discussion

The botanical affinity and appropriate taxonomic assignment of woody specimens from the Gondwana area is uncertain. Walton (1923, p. 104) discussed the general agreement in features of a number of examples of secondary wood found in Gondwana deposits and concludes that: "There was evidently at this period a widespread group of plants . . . . which differ from the typical *Dadoxylon* in the tendency to have uniseriate pitting in the tracheids (although biseriate araucarian pitting does occur) and in the tendency of the pits to be separate and circular." The Horlick specimen described here seems to belong in this group. Walton tends to emphasize the Triassic age of *Rhexoxylon* species which are best known in Beaufort and Stormberg beds (Triassic) of South Africa; the other species of *Dadoxylon* he mentioned still are generally regarded as Permian. *Dadoxylon pedroi* Zeiller (1895) (=*Trigonomyelon pedroi* (Zeiller) Walton (1925, p. 13)) from the *Mesosaurus*-bearing Iraty shale in Brazil, and *Dadoxylon indicum* and *D. bengalense*, which Miss Holden (1917) obtained from the Barakar beds of India, are assigned to the Early Permian (King, 1958, p. 56-57). Extremely polystelic forms of *Rhexoxylon* are characteristic of the Early Mesozoic (Kräusel, 1956) and are there associated with the *Thinnfeldia* assemblage. It is clear that plants having the same type of secondary wood were abundant in the Gondwana upper Paleozoic. It seems most reasonable to consider *Antarcticoxylon* belonged to the latter group.

The affinities of this group of gymnosperms are likely to remain obscure for some time to come. However, Miss Holden's comparison of *Dadoxylon indicum* with *Ephedra*, the striking concurrence of scandent and anomalous habit in the *Gnetales* as well as in *Rhexoxylon*, and, above all, recognition in recent years of the persistent occurrence of gnetalean pollen since the late Paleozoic (Wilson, 1959, p. 35-40; Scott, 1960), should not be lost sight of. Affinities will never be established on the basis of poorly preserved secondary wood alone, but woody remains in conjunction with other lines of evidence contribute circumstantial evidence that greatly narrows the range of probably affinity. The very imposing antiquity of the gnetaleans is best illustrated by study of their pollen and this agrees well with the remarkable diversity of habit, which must indicate longstanding divergence, which is present now within the three extant genera of the group. The occurrence of vessels in the gnetalean wood must, of course, be regarded as a relatively coenogenetic characteristic, reflecting a general tendency but probably actually originating separately in all the three modern groups assigned to this class of plants (Chlamydospermae). Walton (1925, p. 9) has described "a disturbance in the seriation of the tracheids" in a specimen from South Africa which he identifies with Rhexoxylon priestleyi as "due to spaces which must represent the position of thinwalled cells, and into which the adjoining tracheids seem to bulge (Plate III, Fig. 13, y)." He has also suspected the presence of such cells in wood of Rhexoxylon tetrapteridoides. It does not take much imagination to see in these features a possible origin for gnetalean vessels. There would seem to be a distinct possibility that Welwitschia, Gnetum, and Ephedra trace their ancestry, through Rhexoxylon and possibly Antarcticoxylon, into the late Paleozoic. Even the distribution of the modern representatives is suggestive of ancient gondwanide dispersal.

Evidence regarding the occurrence of Antarcticoxylon in the central range of the Horlick Mountains may be summarized as follows. Neither the specimen here described from the Horlick Mountains nor Seward's specimen first described from the Priestley Glacier is very well preserved. The specimen from Priestley Glacier shows a suggestion of anomolous growth which still seems somewhat inconclusive, and that from the Horlick Mountains is entirely inconclusive on these points. Under the circumstances, it is impossible to deny the possibility of a relationship to Rhexoxylon, but the evidence is inferential and not to be relied on as indicative of early Mesozoic age.

WOOD OF MIXED PETRIFACTION

Sample H-19 consisted of iron-stained, mineralized, woody fragments which showed a remarkable diversity of preservation. The wood was fragmented, evidently as a result of pressure following incomplete mineralization. Subsequently, siliceous minerals were deposited which served to solidify the fragmented, partially mineralized, woody pieces. The initial mineralization apparently was limonitic and recent weathering of the limonite has caused staining on outer surfaces.

None of these woody specimens showed good preservation of gross features or of areas of primary growth. Areas of limonitic mineralization, however, showed interesting cell wall features which are illustrated at 200 and 500 x on Plate 8. Apparently the same type of gymnospermous wood is represented as by the fusain fragments and the more complete Antarcticoxylon stem previously discussed.

Plate 8, Fig. 1, shows islands and marginal areas preserved by a yellowish to reddish limonitic mineral, with an area of siliceous mineralization intervening. Woody tissue in the siliceous area is represented by skeletal vestiges of cell walls similar to that previously discussed and shown on Plate 6. Similar limonitic islands are shown in Plate 8, Fig. 2, but wood of the surrounding siliceous area is more poorly preserved than in Fig. 1. Apparently silicification occurred during the later part of early diagenesis when the wood had been softened and the outer layers of cell walls (inside the cells) could be removed by transmigrant solutions. Occasionally this could proceed to the point of complete structural degradation of the wood.

Woody tissue enclosed by limonitic material was evidently protected from later diagenetic degradation, as shown by the limonitic patches illustrated in various figures of Plate 8. Figure 3 shows termination of an annual growth ring, late wood on the left, early wood on the right. This illustration should be compared with equivalent illustrations (Figs. 5 and 6, Plate 6; same magnification) of sections from the more complete stem from the Horlick Mountains. All the wood protected within limonitic areas shows relatively thick walls.

An example of this wood is shown at 500 x magnification in Plate 8, Fig. 4, and it appears from this that the interior wall layers may be somewhat swollen and the full wall thickness slightly exaggerated. The middle lamellae are not prominent and the central part of the thickened wall includes a less dense concentration of organic material than might be expected in comparison, for example, with associated fusain. These illustrations provide a basis for evaluating the physical texture and stages of dissolution in woody material even though it is difficult to quantify the information.

FRIABLE WOOD IN SANDSTONE (Specimen H-15)

Another type of woody preservation is illustrated on Plates 9 and 10. The original specimen consisted of a strip of brownish fossil wood embedded in a coarse conglomeratic sandstone, specimen H-15, as shown in Plate 9, Fig. 6. Although the sand was moderately cemented, the wood was friable and relatively pulverulent. Microscopical surface examination with reflected light suggested the need for special methods of preparation in order to examine it in detail. The woody strip did not appear to have been compressed within the sandstone matrix and the parts of four or five annual rings in the specimen are all relatively thick.

The sandstone matrix shown in the upper part of Plate 9, Fig. 6, also shows a surface impression of fossil wood. Presumably, the natural surface of the piece of brown, pulverulent wood, shown along a transverse fracture, would be similar. The surface impression shows a prismatic checking similar to the fusinized fragment illustrated in Plate 5, Figs. 9a and 9b. The same sort of checking has been illustrated by Varossieau

(1949, p. 346, 347, Figs. 5.06 and 5.07) as a result of either chemical (anaerobic) or of fungal degradation. No fungal hyphae have been seen in course of microscopical examination Varossieau found that prismatic checking occurred under anaerobic conditions in about 450 years.

After the rock specimen had been initially photographed, material was sawed from one end for special examination. Parts of the annual rings were coherent enough to hold together for infiltration with hot carnauba wax. Polished surface sections could then be prepared in transverse and longitudinal planes as illustrated in Figs. 1-5 of Plate 9 and Figs. 1-8 in Plate 10.

In these photographs, the carnauba wax infiltrate appears gray and the original cell wall and mineral matter appear dark. Evidently, in spite of its different appearance, this type of woody preservation is rather similar to the limonitic preservation illustrated on Plate 8. Some brownish limonite seems to remain in the wood and I believe that the wood probably was initially preserved by a solid limonitic infiltration; however, most of the mineral has been removed by recent leaching at the outcrop after exposure.

Some of the best preserved areas of transverse sections are shown at 200 x magnification in Plate 9, Figs. 3 and 4. Similar areas at 400 x magnification are shown in Figs. 1 and 7. Figure 2, at 800 x magnification, is a part of the area shown in Fig. 1. Woody tissue showing evidence of distortion is shown in Fig. 5. Occasionally evidence of a biseriate ray can be observed, as in Figs. 3 and 7, but biseriate rays are not common and it seems evident that this wood is very similar to that previously described.

Figure 2 of Plate 9, taken at 800 x magnification, should be compared with Figure 4, Plate 8, at 500 x magnification. The preservation is generally similar with lamellar areas, if anything, a little better shown in Fig. 2 by reflected light. Carnauba wax has penetrated intermediate areas of the secondary walls of cells and degradation of the wall appears most similar to that caused by fungi as illustrated by Bailey and Vestal (1937). Evidently the central layer of the secondary wall has become depleted, but the causal agency is uncertain. Unlike the material studied by Bailey and Vestal, fungal hyphae have not been definitely observed. Varossieau (1949) has shown that over a longer period of time, abiotic or chemical degradation can result in a similar reduction in the amount of organic material. Regardless of the responsible agency, these illustrations show the zones of least stability were the same in the fossil wood of the Horlick Mountains as in a number of gymnospermous woods today. Such evidence is about as compelling as any that a paleobotanical study can provide as an indication of the original composition of the wood. Distribution of lignin and cellulosic materials was probably the same as in the similar modern material studied by Bailey and his colleagues.

Longitudinal sections, prepared in the same way as the transverse sections but oriented differently for polishing, are illustrated on Plate 10. Tangential sections, including uniseriate rays, are shown in

Figs. 1-3. In some areas carnauba wax has penetrated the walls and shows casts of bordered pits in cross section. Similar evidence of pit apertures, without development of the pit chamber, is shown in Figs 6 and 7. Tapered ends of tracheids are well illustrated. Probably, the carnauba strand in the middle of Fig. 4 is occupying central wall space in which the middle lamella and adjacent central wall layers have largely been removed. Pit apertures in the inner layer of the secondary wall are more or less intact.

Figures 5 and 8, Plate 10, are believed to represent ray cells in radial section. Presumably, these cell walls originally were cellulosic and perforations may either represent plasmodesmal connections or very small simple pits. Commonly nonlignified ray cell walls are preserved in fossil wood when associated ligno-cellulosic elements have been degraded. Apparently this explanation also may apply here.

FOSSIL LEAVES AND SEEDS

Notes on Preparation

Attempts were made to improve resolution of megafossil detail by etching and peeling procedure, but those efforts were largely unsuccessful. The best detail was observable on naturally weathered surfaces observed in dry condition. The matrix of the one collection in which megafossils were present is very dark and carbonaceous. No improvement in appearance was gained even by observing the weathered surfaces wet with xylol. Peel results on etched fragments of leaves freshly exposed in the dark matrix were disappointing. It seems evident that all carbonaceous material of leaf or seed substance that remains is in a metamorphic state equivalent to semianthracite. Thus it hardly responds to chemical treatments and the physical distinction of the fossils is best brought out under natural conditions of Antarctic weathering.

GLOSSOPTERIS Bgt. nom. cons.

The glossopterids are usually classified in three genera (*Glossopteris*, *Gangamopteris*, and *Palaeovittaria*) on the basis of leaf outline and venation (Srivastava, 1956), Surange and Srivastava (1956) suggest that this classification is highly artificial. Cuticular features indicate at least six genera are represented among the numerous species, but groups defined on the basis of stomatal and other epidermal features do not coincide with those based largely on venation. Their Group 2 (which includes the type species, *G. browniana*, and must, therefore, retain the name *Glossopteris*) has a moderately thick cuticle, straight-walled epidermal cells, and longitudinally, but irregularly, oriented stomata on both upper and lower surfaces. Five species, all assignable to *Glossopteris* on the basis of venation and configuration, are included in Group 2.

Group 1 includes species with sinuous epidermal cell walls, four normally assignable to Glossopteris, and two which would be customarily identified with Gangamopteris.

Group 3 includes Glossopteris indica, G. conspicua, and a species doubtfully assigned to Gangamopteris.

Group 4 includes three species normally referable to Glossopteris and a specimen of Gangamopteris very similar to the type species of Gangamopteris, G. cyclopteroides. This group has a relatively thick upper cuticle, thin lower cuticle, straight-walled epidermal cells, and sparse stomata confined to the lower surface. Presumably, this group will retain the name Gangamopteris and the principal distinction would appear to be found in distribution of stomata, on the lower surface of the leaf only in Gangamopteris (dorsistomatal), and on both leaf surfaces (amphistomatal) in Glossopteris.

Group 5, with sinuous epidermal cell walls, includes two species referable to Gangamopteris. Group 6 includes one species assignable to Glossopteris and the one species usually differentiated as Palaeovittaria.

A rather similar taxonomic problem was disclosed by Pant (1958) in the study of Glossopteris specimens from Tanganyika. Apparently unaware of Srivastava's extensive study, he adopted a somewhat different approach and described forms chiefly distinguished by cuticular features as new species. In addition, the new genus Rhabdotaenia is described which may also be allied with Glossopteris.

It is noteworthy that three of the Glossopteris species which are liable to be confused, fall into different groups of Surange and Srivastava. The idea that glossopterid species have an overlapping leaf size and nervation is, in general, confirmed. These findings cast doubt on the significance of determination not based on cuticular as well as megascopic observation, and they may help to explain why detailed stratigraphic zonation has not been possible, based on determination of glossopterid species identified solely by leaf outline and venation. Unfortunately no epidermal features can be determined for any specimens from Mount Glossopteris that have been examined. Lack of other information makes it necessary to utilize the traditional concept of Glossopteris even though it embraces an alliance of forms that exceed the normal range of variation in more critical characteristics diagnostic of a genus. Stratigraphic application of these results probably has general significance because there seems no reason to doubt that all the glossopterids are interrelated. More detailed evaluation is necessarily doubtful or more difficult since these established glossopterid taxa are so largely based on distinctions of convenience.

GLOSSOPTERIS INDICA Schimper
Plate 11, Figs. 1a, 1b; Text Figs. 4, a, b, c

Leaves of Glossopteris from the Horlick Mountains agree remarkably well with those reported from the Mount Buckley nunatak on Beardmore Glacier by Seward (1914), from Hill B_1 south of the Ferrar Glacier at McMurdo Sound (Edwards, 1928), and with forms customarily assigned to this species elsewhere. They occur with coal deposits at Mount Buckley just as they do at Mount Glossopteris in the central range of the Horlick Mountains. Parts of three fairly well preserved leaves are shown on weathered surfaces in Figs. 1a and 1b of Plate 11; other fragments were found in splitting the matrix but, owing to the dark leaves and dark matrix, are almost impossible to photograph. Photo line tracings reproduced at twice natural size to illustrate portions of laminae shown in Plate 11, Fig. 1a, are given in Figs. 4a and 4b. The types of veinlet anatomosis and ribs on the midvein are characteristic. Nervation is much less evident on the smooth specimen shown on Plate 11, Fig. 1b. The same type of venation is evident when viewed at low magnification, but the relief along the veins, present on the specimen shown in Fig. 1a, is nearly wanting. Probably, the specimen shown in Fig. 1b represents an upper surface, and 1a, the lower, more strongly veined surface of the leaf. One specimen showing frayed and matted fragments of several leaves, is shown at 2 x magnification in Fig 4c. Deposits of matted leaves, even though degraded, are more likely to occur near the growth site of the plants.

SAMAROPSIS Goeppert

According to Goeppert (1864), the genus included plants with: fruits samaroid, membranous, flattened, with winged margin, monospermic. The genus was monotypic when proposed so there is no question regarding its type species. Florin (1940) is in error in saying that Samaropsis has no type species. The genus evidently is artificial to the extent that it cannot be assigned within a particular family of plants, but all plants having seeds of the Samaropsis type surely must be gymnospermous. Thus, the taxon is a form genus with a broad, but nonetheless definite, range in its affinity. The type species S. ulmiformis Goeppert is illustrated by three or four specimens from the Permian shale at Braunau which may not all be conspecific. The specimen shown in Goeppert's Plate 28, Fig. 10, which as he notes (p. 310) is mistakenly labelled "19" on the plate, appears to best correspond to the description and should be regarded as the holotype of this species. Goeppert's descriptions do not reflect a modern understanding of these fossils, but his nomenclatural types are essential for fixing the consistent application of the names within ranges occasioned by permissible interpretations of circumscription. Florin's modern description (1940, p. 297) paraphrased below, is necessarily based on a better interpretation.

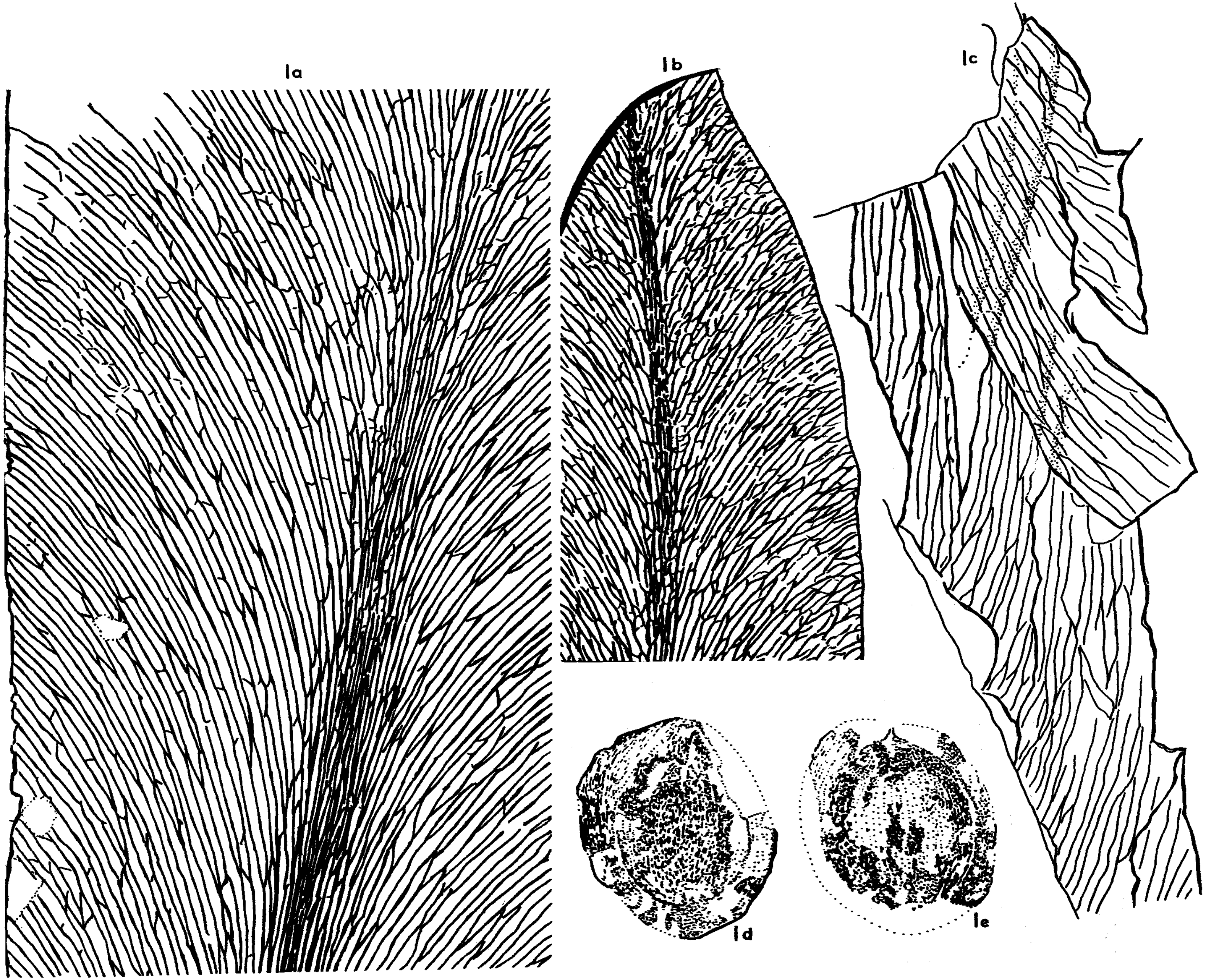

Fig. 4. Line tracings of venation of Glossppteris indica, G. (?) sp. and seeds of Samaropsis longii

Description

[Plants having] seeds atropous, bilaterally symmetrical, flattened, lenticular in cross section, circular, oval or cordinate in side view, closely invested laterally by a clearly marked "wing" developed from the sarcotesta, pointed or sometimes weakly emarginate at either or both the apex and base, point of attachment [hilum, sometimes (?)] developed unilaterally. Upper surface of seed either ribbed, striated or, occasionally, smooth. Usually preserved as coalified compressions or impressions which only denote affinity with Paleozoic gymnosperms. Differing from seeds of Cordaicarpus only in greater breadth of the marginal "wing."

Florin tends to emphasize the asymmetrical hilum of some forms, possibly because of the mode of attachment in walchian seeds with which he was principally concerned. This characteristic was not noted by Goeppert and is not definitely indicated by examples from Antarctica described here. A significant minor asymmetry is often difficult to distinguish from incidental variation modified by accidental factors affecting fossil compression. Forms that are definitely asymmetric and assignable to the walchians probably should be segregated from Samaropsis.

Samaropsis longii n. sp.
Plate 11, Figs. 3, 4; Figs. 4d, 4e

Two small, orbicular, flattened seeds were found on the same rock surfaces associated with the Glossopteris leaves illustrated on Plate 11. The two are shown photographed at 5 x magnification on Plate 11, Figs. 3 and 4 and, also, are illustrated by photo line tracings in Figs. 4d and 4e. Their general outline is oval to nearly circular, 4-1/2 to 5 mm in diameter. The marginal wing is nearly a millimeter wide and the central sclerotestal area is about 3-1/2 mm across. The internal nucule is not clearly shown, but may have been about 2-1/2 mm at the widest point. One of the seeds shows a faint micropylar projection from the testa (Plate 11, Fig. 3; Fig. 4e). The other example, broken a little differently, seems to show a slight micropylar elongation of the testa and narrowing of the wing. I am unable to discover any trace of a hilum scar. The seeds are in a rather coarse, silty, carbonaceous matrix that is hard, owing to siliceous cementation, and has not preserved any finer surface features. The seeds consist of high rank coaly fragments derived by compression of the seed tissues. Compression folds, such as would occur if the seeds had been fleshy or spheroidal, are lacking. Consequently, it is reasonably certain that the seeds were originally flattened or platyspermic.

As these seeds appear a little different from others for which names are available, it seems desirable to propose a new species based on them called Samaropsis longii n. sp., in honor of Mr. W. E. Long, a member of the party that initially explored Mount Glossopteris, who made these collections.

Diagnosis

Seed, platyspermic, flattened, not fleshy, ovate to orbicular, about 5 mm diameter; marginal wing slightly less than a millimeter wide, nearly continuous, slightly narrower near the micropyle; pollen chamber probably present; hilar scar not evident.

Holotype

Specimen illustrated on Plate 11, Fig. 3, Fig. 4e, from Sample H-25, coal measures central range of the Horlick Mountains. The specimens have been assigned nos. 41996 and 41997 and deposited in Washington, D. C., at the U. S. National Museum.

Discussion

Seeds that closely resemble those of *Samaropsis longii*, but are smaller, have recently been described by Thomas (1958) in association with a fertile glossopterid called *Lidgettonia africana*. This material came from a locality 35 kilometers northwest of Pietermaritzburg, Natal, Union of South Africa, probably from the upper part of the Ecca division of the Karroo system. The wing appears a little broader on the sides than on *Samaropsis longii*, and the central area slightly more elongate, but aside from this and their smaller size (diameter 2-3 mm), the seeds are essentially similar. Walton (1929) has illustrated seeds from the Upper Wankie sandstones of Southern Rhodesia that are very similar to those described by Thomas. Zeiller (1902) described very similar seeds from the Upper Talchir or Barakar series in India that he, in agreement with Feistmantel, was inclined to attribute to *Voltzia*. He illustrated two forms, one (his Fig. 9) 3-4 mm long x 2-2-1/2 mm wide, and the other (his Fig. 10) 3-5 mm long x 2-1/2 - 3/1/2 mm wide, both with a narrow lateral wing, which he regarded as conspecific. The proportions of these seeds are a little different from *Samaropsis longii*, although they probably represent at least the same family of plants. I am inclined to question their attribution to *Voltzia* and I believe it is desirable to propose a name of specific reference for them.

SAMAROPSIS THOMASII n. sp.

I suggest that these small platyspermic seeds, which are well represented from probable lower Permian of both Southern Africa and India, be referred to *Samaropsis thomasii*, sp. nov. The specimen, well illustrated by Thomas (1958) at 3 x magnification in his Plate 22, Fig. 2, may be regarded as the holotype. The species has been amply characterized by his description (Thomas, 1958, p. 185) as well as by the descriptions of Walton and Zieller. It seems particularly appropriate that Dr. Thomas' name should be associated with this form which is evidently a widespread and characteristic element of the lower Gondwana plant assemblage.

Seeds much smaller than any of these have recently been described from the Raniganj coal field in India and the Mhukuru coal field in Tanganyika by Pant and Nautiyal (1960). These examples are coalified compressions, appropriate for detailed examination by maceration procedures. It is unfortunate that all available Antarctic material has been so strongly altered that these techniques are not applicable and a very close comparison is impossible. Even though new genera have been proposed by Pant and Nautiyal, the general conformation of some of these seeds is not very different from small specimens customarily assigned to Samaropsis.

Surange and Lele (1957) also recently described Samaropsis goraiensis from the Talchir series in the South Rewa basin, India. S. goraiensis is a little larger than S. longii (7 x 4 mm), distinctly cordiform, with the nucule pointed at both ends. Samaropsis etheridgei Walkom (1922) has seeds 10 mm long x 9 mm wide in which the nucule is truncate at the base. This species of Queensland and the upper Bowen series (Triassic) is considerably younger than the others that are mentioned. Samaropsis ganjrensis Saksena (1955, p. 74-75) from the lower Gondwanas below the Barakar coal bed is elliptical, 12 x 10 mm in diameter, only slightly longer than S. etheridgei. The wings are broader distally and are interrupted by a distinct hilar notch.

A good many other species based on seeds have been described. Those mentioned seem most comparable to S. longii. Perhaps some weight can be placed on the similarities of this group of species for purposed of age determination. In spite of the superficial nature of biocharacters that can be directly observed, growth, fertilization and dispersal of seeds has such basic importance in the survival and spread of species that the gross similarities may not be incidental. I believe it is significant that all but one of these small seeded species of Samaropsis from the Gondwana area probably are derived from Permian deposits.

OTHER TYPES OF FOSSIL MATERIAL

ARTHROPHYTE (?) stem

One sandstone specimen from sample H-23 showed a flattened axis with a coaly rind which was thicker and protruded from both sides. The elliptical pith area is about 26 mm x 16 mm as shown in Plate 11, Fig. 2a. The coal rind is about 2 mm thick on top and bottom, but is expanded to a thickness of more than a centimeter on both flanks. The thickened coaly extensions on the flanks seem to continue the length of the specimen (about 11 cm) without significant change as shown by five transverse slices. A second disconnected piece about 7 cm long and similar transverse dimensions, probably was broken in the field from the same stem. There is no sign of appendages and no trace of nodal structure can be seen. A very faint indication of ribbing on the pith mould, with shallow linear indentions nearly 2 mm apart, shows on one exposed end. Possibly, the fossil may represent a corticated arthrophyte axis.

With the hope of resolving some type of tissue structure in the coalified rind, two of the transverse sections were brought to a high polish, one of which is illustrated in Plate 11, Fig. 2a. The polished surface of the rind showed an inner zone 1/2 to 2 mm thick, which was more coaly and had linear checks. The outer rind could not be highly polished. Figure 2b, Plate 11, shows the zone of contact between the highly polished inner coaly zone (above) and the outer dull zone (below), as viewed under immersion with vertical illumination. The dark pits and craks of the inner zone are filled by mineral matter. The darker areas of the marginal (lower) zone also are mineral-filled, but the mineral filling seems to show vestiges of thin-walled cellular tissue. One of the best areas is illustrated in Fig. 2c at 400 x magnification. In spite of this suggestion of organized tissue, no definite histological features were observed.

Figure 2a, Plate 11, also shows features of the sandstone matrix with small, black, coaly granules. The zone of lighter coloration at the top and on the right reflects the depth of weathering. The central area is relatively dense and gray and probably, in part, is cemented by siderite.

INVERTEBRATE TRAILS

The specimen illustrated in Plate 11, Fig. 5, shows trails of invertebrate organisms of which no other trace has been detected. Scarcity of animal fossils in Southern Hemisphere, and especially Antarctic, coal measures lends additional interest. Despite their vermicular trajectory, these trails probably were not caused by worms. The matrix is a coarse, friable sandstone, platy and thin-bedded, with darker clay and tiny carbonaceous specks more abundant along the bedding planes. Macerations were prepared from this matrix with the hope that friability signified lesser metamorphic alteration of acid resistant types of microfossils. Some spore and pollen types were recovered (Sample H-10-1/2, Maceration 946, see Plate 4) but their alteration was similar to those from rocks more solidly cemented. No scolecodonts were observed. This negative evidence probably has some significance because samples containing the filled vertical types of small animal burrows that are usually attributed to worms, often provide circumstantial confirmation from associated microfossils consisting of chitinous annelid jaw parts.

COAL STUDIES

Long (1959a, 1960) was able to observe numerous coal beds on the slopes and near the summit of Mount Glossopteris. Neither time nor equipment was available for detailed recording or sampling of any of the coal beds, which apparently range from a few inches to minable thickness and vary in grade of purity. Two hand specimens were obtained which were large enough to provide material for coal analysis and give qualitative information about the deposits. Unfortunately, the details of the coal measures stratigraphy were not specifically noted when collections were made. The analyses suggest that both specimens came from adjacent deposits. No inferences can be made as to grade and characteristics of coal beds from hand specimens, but they do provide an indication of stage of metamorphism or rank. The rank of a coal suggests probable characteristics in utilization and has further implications geologically. An effort has been made to obtain further information about the coal that might be of significance.

PROCEDURES

Samples were obtained for chemical analysis by trimming the specimens with bonded abrasive dry cut-off saw. A general representation was taken from the best specimen (H-16), but the other (H-20) included only one thick vitrain band and a little attrital coal that was all too obviously impure. Consequently, only the better coal was included in the analytic sample of the H-20 specimen.

Reserve pieces from each specimen were polished normal to the banding and photographs taken at low magnification to illustrate lithologic features (Plate 12, Fig. 2; Plate 14, Fig. 2). Smaller pieces from each were prepared in thin section for study by transmitted light according to the method of Thiessen, Sprunk, and O'Donnell (1938), and in surface section according to methods described by Stach (1949). One layer of impure attrital coal adjacent to the band analyzed from the specimen at locality H-20 was digested in hydrofluoric acid and distribution and characteristics of detrital resinous bodies were noted (Plate. 14, Figs. 3, 4; Plate 15, Figs. 1-10).

If it is possible subsequently to obtain accurate samples of individual coal beds, it should be possible to quantify these essentially qualitative types of results. The specimens provide a valuable indication of the kinds of coal to be expected in the area of the central range of the Horlick Mountains.

COAL ANALYSES

Standard coal analyses for the two Horlick specimens and for other coal samples from Mount Gran in the Granite Harbor area of South Victoria Land are given in Table 1. The Mount Gran samples were obtained by Mr. John J. Mulligan of the U. S. Bureau of Mines and are included here for comparison. All of the coal analyses were made by the Coal Analysis Laboratory of the U. S. Bureau of Mines, under supervision of Mr. Roy F. Abernethy.

Few coal analyses have been available for coal deposits in Antarctica in spite of the fact that Antarctic coal fields may rank among the largest in the world and, thus far, coal is virtually the only mineral resource of possible economic value to have been discovered there. The tabulated

Table 1.--Standard analyses of Antarctic coal specimens and samples

Coal sample identification	Condition 1/	Proximate, percent: Moisture	Proximate, percent: Volatile matter	Proximate, percent: Fixed carbon	Ultimate, percent: Ash	Ultimate, percent: Hydrogen	Ultimate, percent: Carbon	Ultimate, percent: Nitrogen	Ultimate, percent: Oxygen	Ultimate, percent: Sulfur	Calorific value, B.t.u.	Specific gravity	Ash fusibility: Initial deformation temperature, °F	Ash fusibility: Softening temperature, °F	Ash fusibility: Fluid temperature, °F
CGL-50 (H-20)	A	3.2	9.1	60.1	27.6	2.4	60.9	1.2	7.4	0.5	9,750	1.76	2910+	...	...
Mt. Glossopteris,	B	..	9.4	62.1	28.5	2.1	62.9	1.2	4.8	.5	10,070	...	...	...	...
3/4 mi. W. of,	C	..	13.1	86.9	..	2.9	87.9	1.7	6.7	.8	14,070	...	...	...	...
Anal. G-45479	D	..	10.58	89.42	...	...	92.55	...	...	...	...	...	...	...	...
	E	...	...	...	...	...	...	...	...	...	13,906	...	...	...	...
CGL-51 (H-16)	A	3.2	10.4	74.6	11.8	3.0	75.4	1.3	7.8	.7	12,290	1.58	2840	2910+	..
Mt. Glossopteris,	B	..	10.7	77.1	12.2	2.7	77.9	1.3	5.2	.7	12,690	...	...	...	...
near CGL-50	C	..	12.2	87.7	...	3.1	88.7	1.5	5.9	.8	14,460	...	...	...	...
Anal. G-45478	D	..	11.02	88.98	...	...	86.9	...	...	...	...	...	...	...	...
	E	...	...	...	...	...	...	...	...	...	14,083	...	...	...	...
12-23-1 Mt. Gran	A	14.9	5.4	66.6	13.1	2.7	67.1	.4	16.4	.3	10,110	1.88	2470	2520	2570
#1 bed, 4.1 ft.	B	..	6.3	78.3	15.4	1.2	78.9	.5	3.7	.3	11,880	...	...	...	...
25-lb. channel sample	C	..	7.5	92.5	..	1.4	93.3	.5	4.5	.3	14,050	...	...	...	...
Anal. G-79508															
12-23-2 Mt. Gran	A	14.1	4.5	71.6	9.8	2.6	72.6	.6	14.2	.2	10,890	1.86	2260	2360	2650
#3 bed, 2 ft.	B	..	5.3	83.3	11.4	1.2	84.5	.7	1.9	.3	12,680	...	...	...	...
25-lb. channel sample	C	..	6.0	94.0	..	1.4	95.4	.8	2.1	.3	14,320	...	...	...	...
Anal. G-79514															
12-24-4 Mt. Gran	A	7.8	10.9	66.8	14.5	2.5	68.9	.9	12.1	1.1	10,600	1.82	2420	2470	2720
#5 bed 0.7 ft.	B	..	11.8	72.5	15.7	1.8	74.7	.9	5.7	1.2	11,490	...	...	...	...
15 lb. block specimen	C	..	14.0	86.0	..	2.1	88.5	1.1	6.9	1.4	13,620				
Anal. G-79515															
12-23-3 Mt. Gran	A	1.5	4.4	76.1	18.0	.6	76.7	.0	4.7	.0	10,590	2.17	2360	2420	2620
#1 bed (?) float	B	..	4.5	77.2	18.3	.4	77.8	.0	3.5	.0	10,750	...	...	...	...
specimen at dolerite	C	..	5.5	94.5	...	.5	95.2	.0	4.3	.0	13,150	...	...	...	...
sill. Anal. G-79516															
1-10-1 Mt. Gran	A	6.2	6.2	75.0	12.6	2.4	74.5	.8	9.3	.4	11,620	1.73	2890	2910+	..
#1 bed (?) float	B	..	6.6	80.0	13.4	1.9	79.4	.9	4.0	.4	12,390	...	...	...	...
specimen at(?) dolerite	C	..	7.6	92.4	...	2.1	91.8	1.0	4.6	.5	14,310	...	...	...	...
sill. Anal. G-79520															
12-23-1E Mt. Gran	A	19.5	4.3	67.8	8.4	3.3	67.6	.4	20.1	.2	10,250	1.90	2100	2420	2700
#1 bed, top foot,	B	..	5.3	84.2	10.5	1.4	84.0	.5	3.3	.3	12,730	...	...	...	...
1 quart sample	C	..	5.9	94.1	...	1.5	93.9	.6	3.7	.3	14,220	...	...	...	...
Anal. G-79511															
12-23-1F Mt. Gran	A	16.4	4.5	72.0	7.1	3.0	71.8	.4	17.5	.2	10,860	1.82	2420	2520	2730
#1 bed, 12-18 in. from	B	..	5.3	86.3	8.4	1.4	85.8	.5	3.6	.3	12,980	...	...	...	...
top, 1 qt. sample	C	..	5.8	94.2	...	1.6	93.7	.5	3.9	.3	14,180	...	...	...	...
Anal. G-79512															
12-23-1I Mt. Gran	A	14.7	7.3	64.2	13.8	2.7	65.4	.4	17.4	.3	9,770	1.90	2260	2310	2470
#1 bed, 36-49 in. from	B	..	8.6	75.3	16.1	1.3	76.7	.4	5.2	.3	11,450	...	...	...	...
top, 1 qt. sample	C	..	10.3	89.7	...	1.5	91.4	.5	6.2	.4	13,650				
Anal. G-79513															
1-9-5 Mt. Gran	A	1.2	4.7	84.4	9.7	.5	85.5	.0	4.2	.1	11,950	2.13	2020	2130	2520
#1 bed contact	B	..	4.7	85.5	9.8	.4	86.5	.0	3.2	.1	12,090	...	...	...	...
at igneous sill	C	..	5.3	94.7	...	.4	95.9	.0	3.6	.1	13,410				
Anal. G-79519															
12-13-2 Mt. Gran	A	8.8	4.5	78.0	8.7	2.3	77.0	.5	11.2	.3	11,690	1.81	2180	2360	2600
#1 or #2 bed,	B	..	5.0	85.4	9.6	1.5	84.5	.5	3.5	.4	12,830	...	...	...	...
outcrop specimen	C	..	5.5	94.5	...	1.6	93.4	.6	4.0	.4	14,180	...	...	...	...
Anal. G-79502															
12-14-4 Mt. Gran	A	9.7	8.5	59.0	22.8	2.0	61.0	0.5	13.6	0.1	8,960	2.05	2420	2470	2700
Float specimen	B	..	9.4	65.4	25.2	1.0	67.6	.5	5.5	.2	9,920	...	...	...	...
from E. slope	C	..	12.6	87.4	...	1.3	90.3	.7	7.5	.2	13,260	...	...	...	...
Anal. G-79506															
12-26-1 Mt. Gran	A	4.2	5.6	83.1	7.1	1.1	83.3	.2	7.6	.2	12,050	2.03	2050	2130	2360
Float; moraine at	B	..	5.8	86.8	7.4	.7	87.5	.2	4.0	.2	12,570	...	...	...	...
junction of glaciers	C	..	6.3	93.7	...	.7	94.5	.3	4.3	.2	13,580	...	...	...	...
Anal. G-79507															
12-13-4 Mt. Gran	A	.9	2.8	58.2	38.1	.4	58.5	.0	3.0	.0	8,180	2.47	2060	2100	2360
Float specimen of	B	..	2.9	58.6	38.5	.3	59.1	.0	2.1	.0	8,260	...	...	...	...
impure coal	C	..	4.7	95.3	...	.5	96.0	.0	3.5	.0	13,430	...	...	...	...
Anal. G-79054															

1/ Conditions A-E refer only to the analysis and calorific value of the coal. A, as received; B, moisture-free; C, moisture- and ash-free; D, moisture- and mineral-free; E, mineral-free (moist).

Table 1. Standard analyses of Antarctic coal specimens and samples

analyses are standard analyses in the sense that they have been derived according to carefully standardized laboratory procedures used generally for purposes of analytic comparison in the United States and Canada. Thus, these analyses are suitable for comparative evaluation, subject to original limitations inherent in the samples.

Since no adits or mine openings are available, all the specimens and samples necessarily were obtained from natural outcrops or, in some instances, from coal float. Material of this nature, of course, cannot be relied on for evaluation of purity of coal beds, and in this regard can be accepted solely as a qualitative indication of kinds of coal that happened to be present. As all the samples were obtained on the surface of deposits or very close to the surface, some of them must have been subject to long exposure and weathering. Moisture values, in particular, are likely to be incidentally variable. Although most of the Antarctic continent is covered by glacial ice, moisture content of the air is low and the climate, in general, is extremely arid. The samples are probably most comparable with those of high rank coal from outcrop in an arid climate. On the other hand, owing to the very low mean annual temperature, chemical alteration near the outcrop is probably less rapid than in arid climates of the Temperature Zones. The analyses probably provide a general indication as to the relative rank (stage of metamorphism) of the coal, and other characteristics not likely to vary as a result of arid weathering or according to local conditions of deposition.

The two specimens obtained on Mount Glossopteris show virtually the same values for moist, mineral-free, fixed carbon (about 89 percent). This amount of fixed carbon corresponds with that of semianthracite. The physical characteristics of the coal also confirm this estimation of rank. The coal measures observed along the Antarctic escarpment are known to be intruded by intruded by igneous sills and a thick igneous sill is now known to occur some distance stratigraphically above the upper coal on Mount Glossopteris (W. E. Long, personal communication, March 1961). The igneous intrusion probably was sufficient to cause partial devolatilization and alteration of rank. The fact that fixed carbon of both of the beds analyzed is so nearly the same on a mineralfree basis of calulation, suggests that the specimens may have come from very nearly the same horizon.

Igneous sills are much closer to the coal beds in the Mount Gran area of Victoria Land (Fig. 1). In some places, sills are in physical contact with the coal so that some Mount Gran samples obviously have been affected. In no instance, however, has igneous devolatilization been violent enough to form a vesicular natural coke. Analyses of the lowest rank of coal at Mount Gran (least affected by igneous intrusion) compare rather well with analyses of coal from Mount Glossopteris. Schopf and Long (1960) have suggested that semianthracitic rank may be characteristic of Permian coal in central Antarctica and indicative of pre-intrusive loading.

Only an incomplete analysis is available for coal at Mount Buckley from the upper part of the Beardmore Glacier (David and Priestley, 1914, p. 250). This coal was noncoking, had a moisture content of 3.16 percent, 14.5 percent volatile matter, 68.84 percent fixed carbon, 13.43 percent ash, and 0.27 percent sulfur. These determinations, of course, are not exactly comparable with values obtained under modern standard conditions of analysis. However, this coal, too, is evidently relatively high rank, probably within the range for semianthracite. A dolerite (diabase) sill also is present in this area at some distance from the coal (Debenham, 1921).

PETROLOGIC FEATURES

Lithologic features of the coal from Mount Glossopteris are illustrated on plates 12-15. The character of banding is shown by polished surfaces of the two best specimens in Fig. 2 of Plate 12, and Fig. 2 of Plate 14, enlarged 2-1/2 times natural size. Both specimens are sparsely thin-banded, with thin vitrain streaks; they consist predominantly of attrital coal. One vitrain band, about five-eighths of an inch thick, was present in a specimen from the lower bed (locality H-16). Most of the attrital coal from both beds has very dull luster and was derived from degraded, fine-textured, plant debris. This appearance is characteristic of coal from many of the Gondwana deposits since they tend, in general, to be more highly attrital, possibly due to greater allochthony in the original deposits, than coal of equivalent age in the Northern Hemisphere.

Other photomicrographic illustrations on Plate 12 show the character of the attrital coal as viewed by reflected light in surface section after polishing. The vitrinite is even textured, for the most part, with minute black pits which represent dispersed mineral inclusions. Fusinite shards, shown in Figs. 3 and 6, illustrate some cell wall features of plant tissues. Some structures may be seen which resemble spore or pollen coats in cross section, but in no instance is identification fully convincing. It has not been possible to obtain spores directly from this coal by maceration and this is taken as an indication that both exinite and vitrinite at this stage of rank development show little evidence of differentiation according to chemical composition. Surface section photomicrographs on Plate 12 are all shown at 200 magnification.

In one of the specimens interesting plant structures are limited nearly entirely to those preserved as fusain or semifusain. Some representative examples are illustrated by surface section photomicrographs on Plate 13. Almost all the woody tissues in the coal appear to be gymnospermous and similar to that shown in petrified condition on Plates 6-10. Dark areas in the lumens of cells now are nearly all mineral-filled. Much of the fusain has been crushed so that only angular fragments at the thickened corners of cells remain intact. Crushed fusain is shown particularly well in Fig. 6 and in Fig. 4 of Plate 13. In Fig. 4, a thin zone of cells which are relatively intact extends across the center of the illustration. This zone consists of the secondary late wood from an annual ring, similar to those previously discussed in petrified wood. Apparently, these cells were sufficiently strong to withstand compressive forces that shattered the larger tracheids in the early wood. A similar occurrence, mostly preserved as semifusain, is illustrated in Plate 13, Fig. 1. Probably, mineral matter filling the lumens of cells and a greater degree of plasticity has resulted in less actual fracturing of cell walls and less obvious cellular preservation in the woody tissue. Figure 2, of the same plate, shows another example of mineral-filled cells from secondary wood, probably semifusinized, merging with vitrinite in which tissue structure is invisible; a longitudinal section of crushed fusain occupies the top of the figure. A continuation of this same semifusain and mineral-filled structure, with partially vitrinized woody tissue, is shown in Figs. 3 and 5. More highly fragmented fusain is shown in transverse section in Fig. 7. All figures on Plate 13 are at 200 magnification.

The other specimen was smaller and included more impurity. One of the impure fragments associated with the coal was digested by hydrofluoric acid and contained enough carbonaceous matter for coherence after treatment, but became soft and friable. One of these fragments is illustrated at 10 magnification on Plate 14, Fig. 3. This example of very impure, attrital coal shows an abundance of detrital resins, many of which could be esily segregated. A group of segregated resins is shown at 20 magnification in Fig. 4. They tend to be elongate, oval bodies, with some sharp angles which may be original and not caused by breakage.

Both thin sections and surface sections were prepared in an attempt to illustrate the nature of the attrital coal, resinous bodies, and relations of the dispersed mineral matter. Figures 5 and 8, Plate 14, show sections of detrital resins as they appear in surface section, viewed by reflected light, at 200 magnification. A portion of a resinous body at the same magnification is shown in Fig. 7, Plate 14, as it appears in thin section, viewed by transmitted light. The resinous bodies in Figs. 5 and 7 show a variety of slot and "keyhole" openings which are here interpreted as vacuoles or vesicles which have been modified by shrinkage and plastic distortion. The feather edge of the part of a resin shown in thin section, in Fig. 7, illustrates the slight degree of translucency of this high rank coaly material.

Similar resinous bodies, interpreted as fungal sclerotia, have been reported in Talchir coals from India (Pareek, 1958). The detailed study of similar structures by Kosanke and Harrison (1957) suggests strongly that in Paleozoic coal, at least, these structures rarely have any relation to fungi.

Only one portion of a thin section seemed to show color differentiation of cuticular lamellae. This is illustrated in Plate 14, Fig. 6, where the light-colored cuticular strips appear near the center. The irregular light areas on either side represent holes in the section. Feather edges adjacent to the cuticle illustrate the extreme thinness of the area showing color differentiation. Figure 11, Plate 14, also magnified 200 times, shows the characteristic dispersed occurrence of translucent mineral matter, which appears as separate white granules in the picture. A similar section is shown in Fig. 1, Plate 14, at 400 magnification. The large white area in this picture is a hole in the section. Elsewhere in the area photographed, the coal probably averages less than two microns thick. Figures 9 and 10 show unusual types of resinous bodies with a marginal alteration zone as they appear in surface section magnified 400 times.

A good comparison of the range of variation in resinous bodies, both in thin and surface section is shown, as viewed by transmitted and by reflected light, on Plate 15. All figures on this plate are magnified 200 times. The occurrence of mineral matter is illustrated best in thin section Figs. 5 and 8 were the mineral appears white by transmitted illumination. Most of the mineral matter evidently is siliceous since it is hard, and soluble in hydrofluoric acid. The various configurations of resinous bodies are best shown by surface section photomicrographs (Figs. 2, 3, 4, 7, 9, 10). A thin streak of fusain showing tissue structure, a streak of impure vitrinite, and resins in a high mineral matrix are shown in Fig. 4. Figure 1 shows a resinous body in a mineral-rich lamella between two zones with more concentrated vitrinite. The pits in the vitrinite represent mineral inclusions. Very little difference in reflectance can be noted between the vitrinite and resin in this photograph.

If allowance is made for the differences in rank, similarities may be noted between features of Antarctic coal and that of South Africa, India, and Australia (Marshall and Draycott, 1954; Marshall, 1955; Plumstead, 1957). Finely disseminated siliceous mineral matter seems more common in coal of these regions. Resinous bodies are common in some variety in all of these coals, sometimes in unusual concentrations, as in the upper coal bed studied here or in the example illustrated in a previous publication (Schopf, 1952) from the Witbank coal in South Africa. Similar structures have been reported by Pareek (1958) in Talchir coals from India. A point of contrast with Paleozoic coals of the Northern Hemisphere is that resin rodlets, the resinous casts of secretory canals characteristic of the Medullosaceae and probably also present in some other groups of plants, appear to be lacking in the Gondwana coal deposits. Similarly, the globular, resinous concentrates observed here are, at least, much less common in the northern Paleozoic coals. Kosanke and Harrison (1957) have shown, however, that they sometimes occur. This difference in the resins between Gondwana and Arcto-Carboniferous coals is not surprising in view of the absence of medullosan elements from the southern floras, but even known differences of plant origin are not often readily demonstrated by direct study of sections of coal. Contrasts are more generally apparent in the assemblages of microfossils and associated petrified or compressed coalified plant material such as have been discussed in earlier sections of this report.

DISCUSSIONS OF RESULTS

FOSSIL MATERIAL

The plant microfossils reported here generally agree with forms in better states of preservation reported elsewhere in the Gondwana area (Virkki, 1946; Ghosh and Sen, 1948; Rilett, 1954; Balme and Hennelly, 1955, 1956a, 1956b; Lakhanpal and others, 1958; Leschik, 1959; Piérart, 1959; Hoeg and Bose, 1960; Hart, 1960; Rakotoarivelo, 1960). The older glacial and coal measures deposits are generally regarded as Permian, with the glacial deposits dating from late Carboniferous (King, 1958). Alteration of the organic substances composing the highly coalified microfossils of the central range of the Horlick Mountains has made their systematic treatment difficult and their detailed comparison with better preserved material doubtful. Probably better specimens will be obtained later in less altered deposits and through improved methods of preparation which will permit a more satisfactory consideration. Gymnospermous pollen types apparently are most common.

Fusain and mineralized woody specimens all are of a gymnospermous type that is common in the older Gondwana coal measures. One specimen has been identified as similar to Antarcticoxylon priestleyi Seward. The prevalence of fusinized gymnospermous wood in the sediments and in the coal, and similar wood in silicified preservation, strongly suggest dominance of this class of plants during the early period of coal formation in Antarctica.

Leaves of Glossopteris are similar to those previously reported by Seward (1914) from Mount Buckley and by Edwards (1928) in the type area of the Beacon sandstone west of McMurdo Sound in Antarctica. The species represented is one of the most widely distributed throughout the Gondwana area. The leaves are associated with a species of Samaropsis which has small seeds that are specifically distinct, but generally similar to others from Permian deposits of the Southern Hemisphere. A possible arthrophyte axis occurs in one of the sandstones and undulatory trails of an unknown small invertebrate animal complete the list of fossil materials studied.

None of the types of fossils is in conflict with a Permian age assignment but, in the absence of fossils clearly differentiating either the Carboniferous or the Triassic, the age of lower portions of the central range of the Horlick coal measures section, in particular, should be regarded as tentative. Further study based on more ample material should help to resolve uncertainty. Present evidence does not provide as precise an age indication as ome might wish because, although no elements that show unquestionable Mesozoic or Carboniferous age have been determined in the central Horlick area, forms are present that might conceivable range into the Triassic or be older than Permian. Plant microfossils provide greatest promise for future refinement in age determination. Although spores and pollen grains found thus far are not well perserved, their presence and the distinctiveness of some forms have been demonstrated. In all instances, plant microfossils provide for better floristic representation than the megafossils. They are present in beds where megafossils are lacking and preservation of microfossils is less selective. The Beacon Sandstone in Antarctica lacks any clear lithologic basis for correlation. Detailed study of the occurrence and abundance of kinds of spores and pollen seems to offer the best opportunity for establishing zones for correlation within the Beacon Sandstone and for establishing detailed age relations of the Beacon with probable correlatives of the Beacon in other regions where Gondwana age deposits are represented.

CLIMATIC INFERENCES

The similarity of the Gondwana floral assemblages indicates more than similarity in age -- it indicates similarity of past environment. The fundamental implications of geologic and paleontologic studies in Antarctica have recently been summarized by Barghoorn (1961). Higher plants grow in a static relation to the local terrestrial environment. Consequently, their fossil remains provide a unique record of local environmental stress. This is indicated by thickness of growth rings and, possibly to some extent, by the radial splits in stems of trees.

Anomalous distribution of plants is more evident in Antarctica than anywhere else on earth since the present Antarctic climate is most inhospitable. Evidence that good conditions for growth of higher plants once existed in an area of extreme desiccation, low precipitation, and extremely low temperature, demands explanation. The anomalies of distribution are even more evident when the same fossil plants are found both in the extreme tropics and extreme Antarctic of the present day. This situation is best exemplified by _Glossopteris indica_, but it is also supported by other elements of the _Glossopteris_ flora. The preservation of plant material in peaty deposits that can give rise to coal has a further paleoecologic implication, and particularly so when it appears that the same association of plants contributed to the coal forming accumulations in both Antarctic and Tropical areas.

Annual growth rings in secondary wood reflect survival conditions affecting growth, the most important of which is climate (chiefly variations in mosture and temperature), but they also depend on growth response which is a heritable characteristic of species of plants. Plants having inherited an adjustment for annual periodicity will not lack growth rings entirely, even if seasonal periodicity is lacking, although differences between early and late wood will then be minimized. Plants less affected by annual periodicity produce wood that more nearly approaches homogeneity under a truly equitable climate. Different species differ in their response to periodicity of evironmental factors and this response evidently involves a large complex of heritable characteristics. For this reason, as well as variations in local environment, some plants have a greater value in forming an interpretable climatic record than others. Many arborescent plants show an additional morphologic differentiation, evidently a periodicity response, by forming pits on tangential walls of late wood xylem cells. Tangential wall pitting in these plants indicates periodicity of growth, whether climate and environment are variable or not.

Annual growth rings are common to secondary wood of Antarcticoxylon, Dadoxylon, and allied species of Gondwana areas. Growth rings are about as prominent in them as in secondary wood of plants grown in temperate, continental type climates of the present day. From this fact, it seems reasonable to infer a continental type climatic fluctuation and periodicity existed in these areas. It, also, seems reasonable to infer that an apparent lack of growth rings should be indicative of an equitable climate. The character of the growth rings in secondary wood must be generally regarded as indicative and controlled by a response to climate.

In discussing botanical problems in the Arctic, W. C. Steere (1960, p. 3) mentions the too common misconception that the Arctic is the land of "six months of light and six months of darkness," and that some botanists believe that the plants found fossil in northern lands could not have developed under six months of darkness. They thus tend noncritically to explain these occurrences by invoking polar wandering or continental drift (Wegener's hypothesis). Steere points out that periods of the darkness, twilight and very short intervals of light, would come during the winter season when photosynthesis is normally suspended and plants are dormant because of low temperatures. Black spruce and larch now reach the Arctic Ocean well north of the Arctic Circle at the mouth of the MacKenzie River; in general, tree distribution is determined by temperature and perhaps other factors, rather than by the shortness of day in winter. Only a somewhat warmer and more uniform climate would be necessary in order to explain the known occurrences of forests in Arctic regions during earlier eras.

Steere admits, however, that the presence of coal and abundant plant fossils in Antarctica poses the same question in a more aggravated form. This is because there is evidence of the ancient growth of plants much closer to the South Pole than to the North Pole. The South Pole is on a continental land area whereas the North Pole is relatively far from land in the middle of the Arctic Ocean; Spitzbergen is more than ten degrees from the North Pole, whereas Mount Weaver (Blackburn, 1937) is only about three degrees from the South Pole. At the latitude of Mount Glossopteris, about five degrees from the South Pole, the conditions of six months light and six months darkness are fairly closely approximated; the twilight periods are very brief. However, it is clear that difference in polar photoperiodicity are not sufficient basis for the belief that higher plants are necessarily excluded from the extreme polar regions. So far as plant growth is concerned, temperature and moisture relations are much more critical than latitude. By themselves, plants are not likely to provide a precise answer to questions concerning the earth's latitude in ancient times, any more than they do now.

The validity of this point of view also has been suggested by Professor Erling Dorf (personal communication, 1959), who pointed out that some willows ans other angiospermous plants, in fact, do endure long annual periods of semidarkness under cover of deep snowfall in the High Sierras of California. Probably in this region some local areas have as short a growing season as may be found anywhere. However, when the snow cover is gone, for a short interval, temperature and moisture conditions are favorable and significant growth is possible.

Could the earth ever have been warm enough for similar conditions to exist at the South Pole? I would like to pass this question for critical comment to the paleoclimatologist. Growth rings in the secondary wood occurring in the coal measures deposits on Mount Glossopteris show seasonal periodicity and vigorous annual increments of growth comparable to that of coniferous trees growing today under favorable conditions in Temperate climates. The occurrence seems decidely anomalous. The trees, and, by inference, other coal forming vegetation, do not appear similar to the plant assemblage that characterizes the relatively high latitudes of the present Arctic. The permian plants near the present South Pole surely were not growing near any tundra tree line or arborescent ecotone. The plants show evidences of good growth in a periodic climate. However, a climatic explanation will not provide the complete answer to the many geologic problems posed by anomalies in Antarctica.

THE GONDWANA LAND MASS

Sahni (1927, p. 229), in his presidential address to the Geology Section of the Indian Science Congress meeting at Bombay in 1926, said: "Hardly anyone now questions the former existence of a Gondwana continent. But opinion is sharply divided upon the problem as to whether the now far-separated southern countries (with which India is also to be linked, although it lies north of the equator) were connected together by bridging continents now lost in the sea, or whether, as advocated by Wegener and others, they were once directly in contact and fitted together like the parts of a picture puzzle, but have since drifted apart."

David (1950, v. 1, p. 398) said: "Whether or not one accepts the concept propounded by Wegener and supported by Du Toit and others, that India, Australia, Antarctica, Africa, and South America were formerly joined together in one compact land-mass, there can be no question that some connexion existed in Permian time between these now widely separated lands. Such connexion may be inferred from the existence in them of the Gondwana flora, from the striking similarities of their marine faunas, and from the vestiges of a great glaciation that are common to them."

Attempts at reconstruction of the Gondwana land mass always show the largely unknown continent of Antarctica located centrally between the correlated peripheral masses. Consequently, it seems reasonable to suppose that much evidence bearing on proof or disproof of the displacement hypothesis will result from Antarctic studies. Regardless of whether one "believes" in the permanence of continents and ocean basins and their relative positions in late Paleozic time, the same geologic information is pertinent to any discussion of geologic age and ancient climate. The available fossils of the Gondwana areas are strikingly allied. Similarities in stratigraphy also invite comparison, whether one believes this similarity reflects geographic proximity or can be satisfactorily accounted for by another means.

This subject has been extensively discussed by many authors. Selections from much of this literature are referred to in various papers presented at the symposium on the problem of land connections sponsored in 1951 by the American Museum of Natural History (Ernst Mayr, ed., 1952). A very useful review of fossil floras of the Southern Hemisphere has been presented by Theodor Just (1952) in which previous contributions to Antarctic paleobotany are discussed. Teichert (1958) has reviewed the more recent evidence with particular regard to western Australia and cites abundant evidence of thick Paleozoic marine deposits for believing these areas were never connected to another Gondwana Continent. Only along the southern coast of Australia are such deposits wanting. It seems only fair to point out that the southern coast of Australia was the only coast that Du Toit (1937, Fig. 7) shows reconstructed in connection. This connection is with the Adelie and Wilkes coast of Antarctica. Teichert (letter dated July 11, 1961) has pointed out most pertinently that, contrary to statements by David and other authors, striking similarities of marine faunas provide no basis for the assumption of former land connections. The relationships of the land areas should be based on the terrestrial biota. Haughton (1954) has reviewed evidence afforded by distribution of early reptiles, however, and finds no reason for favoring continental displacement. Preston Cloud (1961) has also reviewed the paleobiologic identification of equatorial and polar positions and (p. 194) finds no evidence that requires drift of either the poles or crust of the earth.

Cloud, however, seems to have a misconception (loc. cit., p. 183) about the significance of Virkki's (1937, 1946) work demonstrating the presence of pollen ("winged sporelike bodies") widely distributed in Permian deposits of India and Australia. These pollen grains (*Striaties*), which later work shows are generally associated with *Glossopteris*, are not like the spores of isosporous ferns and they would not by themselves be capable of floral dissemination. They are gymnospermous and Sen (1955), Pant and Nautiyal (1960), and others, have shown their association with *Glossopteris* and even their presence in pollen chambers of associated seeds. There is accumulating evidence that *Glossopteris* represents essentially a group of gymnospermous seed plants (Plumstead, 1958; Kräusel, 1960), possibly allied with the pteridosperms, which, therefore, must have required fertile seeds for dissemination. Even small seeds are too heavy to be carried far by winds, and gymnosperm seeds do not generally remain viable in salt water. Like Kräusel (1960, p. 294), I am content to leave the possibility of continental drift to geophysicists and others, but "Der Botaniker kann nur sagen, dass durch die Vorstellungen Wegeners das Wesen der Gondwana-Floren leichter als auf jedem anderen Wege verständlich würde."

GONDWANA COAL MEASURES DEPOSITS

In addition to occurring generally above tillites and being associated with the assemblage of fossil plants known as the Glossopteris flora, the Gondwana coal deposits have other features in common. In general, the coal itself is more highly attrital in lithologic composition than the prominently banded Arctocarboniferous coals. In general, the coals contain more dispersed (detrital ?) mineral matter. They seem to include a more consistent representation of opaque attritus (micrinite) and dispersed fusain and a lesser amount of vitrain. They are not so generally associated with a definite underclay, or seat earth, in which root traces are prominent. The pronounced alternation of marine and terrestrial facies found in the paralic coal swamps of parts of both western Europe and the central United States is lacking, the marine facies being wanting or not directly related to the occurrences of coal beds. These are characteristics that cannot be readily quantified at the present time and they probably are marked by specific exceptions with which I am not acquainted. They are based on literature, a minimum of field observation in Africa, and on examination of coal from South Africa, Brazil, Australia, and Antarctica. Such a general evaluation must be, to a considerable degree, subjective; nevertheless, the contrasting tendencies, indicated, seem to exist.

I believe these differences signify a difference in regime of sedimentation and coal accumulation which probably also reflect decided paleogeographic contrast. The coal deposits are sometimes highly lenticular and may be exceptionally thick. Even so, extensive commercial deposits exist. No one has ever suggested any of the Gondwana coal beds have the extreme lateral persistence and continuity of well known coal beds in eastern United States and in Western Europe. In the Arctocarboniferous, the lateral persistence of lithologic elements, even though they may be discontinuous, is a no less striking characteristic. The occurrence of particular beds of Gondwana coal is usually restricted to a single mining district though zones including several beds or groups of beds may be correlated farther. With only a few exceptions, the same might have been stated for coal beds of the Arctocarboniferous areas a few years ago, but it would have less justification now, owing to the extensive work of Weller, Wanless, Stout, Moore, Searight, and others.* I believe there is contrast and real difference in regard to sedimentation and stratigraphic continuity which has often been obscured by generalization, by parochial differences in district terminology that do not reflect actual geologic knowledge, and by lack of adequate or equally detailed reports covering related areas.

Except in parts of eastern Australia, the Gondwana coal measures are not highly folded. They are more subject to block faulting. In some areas of South Africa, dolerite (diabase) intrusives, which may alter the coal characteristics over considerable distances, are widespread. Relationships of dolerite to coal deposits in Natal have been discussed by Blignaut

* Wanless (1956) has presented a most effective review of this subject which is soon to be published in full.

(1952) and by Wybergh (1925). Probably very similar relationships will be found to exist in the horst area of Antarctica. Evidence of igneous intrusion is known for at least six of the nine coal localities indicated in Fig. 1.

ANTARCTIC COAL OCCURRENCES

The localities from which coal is known in Antarctica are indicated on the sketch map (Fig. 1). All of the Antarctic coal is probably Permian in age.

Coal was observed on Mount Faraway in the Theron Mountains (No. 1 on the map shown in Fig. 1) by Stephenson (1958) during the recent Fuchs Transantarctic Expendition. The coal locality primarily discussed in the present paper (No. 2 on the map) was observed and specimens collected by W. E. Long while a member of the IGY 1958-59 Byrd Traverse. Six coal beds, ranging up to seven feet in thickness, were observed at the time of the Shackleton Expedition of 1907-9 in the Beacon Sandstone section at Mount Buckley (No. 5 on the map) near the head of the Beadmore Glacier. Mount Buckley is at 85 degrees south latitude -- about five degrees, or a little less than 350 miles from the South Pole. Gould (1935) reported traces of coal at Mount Fridtjof Nansen (No. 4 on the map) as a result of his work on the First Byrd Expedition: On the Second Byrd Expedition in 1936, coal beds were observed by Blackburn (1937) at Mount Weaver (No. 3 on the map) near the head of Thorne (or, as it is now called, Robert Scott) Glacier, in the Queen Maud Mountains, only about 200 miles from the South Pole. Coal was observed in 1911 by Debenham and Taylor at Mount Suess in the Granite Harbor-Mackay Glacier area (No. 6 on the map) during the Second Scott Expedition. Recently, Mount Gran in this same area was revisited by J. J. Mulligan of the U. S. Bureau of Mines, who collected analytic samples of coal. Coal also has been reported from Tent Peak (No. 7 on the map in Fig. 1) by Mrs. Plumstead (1959) as a result of Australian-New Zealand IGY expeditions but no analyses have yet been published. In 1913, Madigan of the Mawson expedition observed coal at Horn Bluff on the Antarctic Coast (No. 8 on the map). Specimens had to be abandoned during the very difficult trip back to base, so no analytic information is available. The Horn Bluff locality is about 2500 miles due south of Sydney, Australia.

The only other coal locality I know of in Antarctica is located on the opposite side of the Antarctic Shield on the margin of the Amery ice shelf at Prydz Bay (No. 9 on the map). The Amery locality is about 5300 miles due south of the southern tip of India, and about 1200 miles away from the central line of coal occurrences on the Antarctic continent itself. Crohn (1959) indicates the rank of this coal is near the dividing line between brown and black coals. A brief study was made of its petrologic character and Balme (<u>in</u> Crohn, 1959) suggested that the assemblage of plant microfossils indicated it, too, is Permian age.

It may be observed that all but one of these localities are roughly aligned across the central horst or block faulted mountainous area of the Antarctic Shield, from about 30 degrees west longitude and continuing to 150 degrees east longitude, extending practically from one side of the continent to the other. All seem to be back of the prominent escarpment which, in part, has been outlined by the recent Byrd Traverse parties (Bentley and others, 1960).

RANK OF ANTARCTIC COAL

Rank of coal, that is its degree of relative metamorphism within the continuous series ranging from unconsolidated peat through meta-anthracite, is of general geologic interest. Coal reacts to metamorphic agencies to serve as a sensitive indicator of low- to medium-grade metamorphic alteration. Relative rank may be determined by reference to standard analytic data of a coal analysis and standard specifications for different ranges of rank based on such data are now generally accepted (ASTM, 1957). Most of the easily measurable properties of coal show a relationship with rank and rank is critical for many purposes of utilization. If Antarctic coal can ever be exploited, its rank will be of primary concern in establishing the presence of suitable deposits.

Rank is a parameter which applies to a coal bed as a whole, since petrologic variations within the coal also influence the values obtainable from selected pieces. Consequently, standard conditions for sampling are just as important as standard analytic procedure for rank to be precisely determined. Standard samples are difficult to obtain in Antarctica, and consequently no precise assignment of rank may be justified on the basis of any analyses now available.

Coal analyses have been given (p. 68-69) for coal from the central range of the Horlick Mountains, and for coal from Mount Gran in the Granite Harbor area of Victoria Land. Available analytic data on coal from Mount Buckley at the head of the Beardmore Glacier has been quoted from David and Priestley (1914). The area between Mount Buckley and Mount Glossopteris in the central range of the Horlick Mountains has been partially explored by the Amundsen expedition and by ground parties from both the First and Second Byrd Expeditions to Antarctica. For the First Byrd Expedition, Gould (1931, p. 182) reports the occurrence of coal in the Beacon Sandstone high on Mount Fridtjof Nansen, but he obtained no specimens for analysis. Near Granite Harbor (Mount Gran) and in other areas, the coal has evidently been altered by igneous intrusion. The lowest rank samples from Mount Gran (presumably least altered by intrusion) are similar to those from Mount Buckley and Mount Glossopteris. The others have higher carbon content and some are obviously graphitic. Dolerite sills and dikes are prominent and have been noted in the Beacon Sandstone at many places along the line of the Antarctic escarpment. Debenham (1921) shows an extensive sill within the coal measures at Mount Buckley, but its influence on the coal beds is not known. A thick diabase sill caps the flattopped mountain southeast of Mount Glossopteris (Long, personal communication, March 1961). The two analyses of coal from Mount Glossopteris show corresponding moisture- and mineral-mater-free values for fixed carbon of about 89 percent, but until more analyses are available, the data will be difficult to evaluate. Only an incomplete analysis is available for coal from Mount Buckley, but this shows coal advanced to about the same rank.

The most thorough analytic study of Antarctic coal has recently been presented by Brown and Taylor (1961) from samples collected on Mount Faraway in the Theron Mountains by the Fuchs Transantarctic Expedition. Analytic values reported by Brown and Taylor are remarkably similar to those from Mount Glossopteris and from Mount Gran. Nearly all show variably high values for moisture and for oxygen that I am inclined to associate with the peculiar conditions of weathering in Antarctica. They point out the analogy with chars of brown or subbituminous coals which have oxygen combined in nonacidic functional groups like the samples from Antarctica. They conclude, however, (loc. cit., p. 224), that prior to thermal metamorphism the coal probably had attained at least medium-volatile bituminous rank.

The fact that one of the samples from the Theron Mountains showed the structure of natural coke is an excellent indication that this coal generally had advanced in rank beyond the noncoking subbituminous stage of metamorphism prior to the time of igneous intrusion. Furthermore, if the usual lack of coke structure were to be accounted for by the coal having been intruded and charred before attaining bituminous rank, the sudden loss of a large amount of moisture and other volatiles should have occasioned much shrinkage. No evident shrinkage cracks have been noted in the hand specimens of Mount Gran and Mount Glossopteris coal I have examined, and the descriptive information given by Brown and Taylor indicates a similar lack of evident shrinkage in coal from the Theron Mountains.

The Mount Faraway coal is regarded as Perminan in age, and is evidently associated with dolerite intrusions. No other geologic data have been given, nor distances of coal sampled from intrusive igneous rock. However, it can be assumed that some samples were close to an igneous contact on the basis of similarity with analyses obtained for coal from Mount Gran, and from the fact that one specimen showed the vesicular structure of natural coke. Most important is the demonstration that this coal did possess the property of coking when it was heated.

A few reports of low rank coal in Antarctica have been given, but apparently only the statement about coal at the isolated Amery locality has been based on analytic information. Only a partial analysis is available for coal from the Amery formation on the other side of the continent, but this is sufficient to show that it is significantly different. Crohn (1959) quotes the Australian C.S.I.R.O. as suggesting that this coal is intermediate between brown coal and bituminous coal -- presumably subbituminous -- in rank. However, Blackburn, who accompained the Second Byrd Expedition, reported (1937, p. 609-610) that at Mount Weaver, near the head of Robert Scott (Thorne) Glacier, "the coal ranged from lignitic to, possibly, bituminous." Mount Weaver is about one hundred miles southeast of Mount Nansen, roughly three hundred miles east-southeast of Mount Buckley, about the same distance southwest of Mount Glossopteris and about two hundred miles from the South Pole. No analytic data have been published on material Blackburn collected at this location, but the low rank of the coal seems anomalous in comparison with other available data. It seems particularly so, since Mount Weaver shows igneous intrusions and was capped, according to Blackburn (1937, and personal communication of June 9, 1961), with a fine-grained, green, igneous sill. The basement rocks were exposed about two thousand feet below. Brown coal was first reported by Taylor (1916) at the Granite Harbor area but Debenham (1921) later seems to contradict this report, and none of the later analyses would confirm it. It seems most reasonable to believe that Taylor and Blackburn confused low grade (impurity) with low rank (degree of metamorphism). Many of the Gondwana coal deposits tend to be more highly attrital and more impure than commercial coals of the Northern Hemisphere. The coal specimens from Mount Glossopteris and Mount Gran that have been studied correspond well with the usual Gondwana types of relatively impure, sparsely banded, highly attrital coal. Low grade, impure coal seems to be common, but the available analyses suggest that any coal from the Beacon Sandstone of the horst area is likely to be low volatile bituminous or higher in rank.

Heat and pressure, exerted over a period of time, cause increase of rank in coal. Coal analytic data from the Theron Mountains, the central range of the Horlick Mountains, Mount Buckley, and Mount Gran all show similar high rank characteristics. Relations of some of these coals, at least, are sufficiently varied with respect to intrusive rocks that the apparent similarity in minimum rank of coal at each locality probably should be explained on a regional, rather than local, basis. If the regional effects of temperature and time can be evaluated, an estimate of the maximum overburden that affects coal deposits would be possible. Such an estimate might be of interest in view of the general difficulty in obtaining geologic information in Antarctica and the necessity for extrapolation of acant information over large areas now covered by ice. Such an estimate would require estimation of the late Paleozoic geothermal gradient and, in cases of altered coal, evaluation of heat provided by igneous intrusives. Igneous intrusives usually have a pronounced local effect and are easily detectable, but intrusives are so generally reported in association with the Beacon Sandstone that an approach similar to that adopted by Blignaut (1952) in South Africa may be necessary in order to assess the effects of regional metamophism apart from those resulting from ingneous intrusion.

High rank may also be associated with pronounced folding or shallow overthrusts, both of which are relatively local in effect and are unknown in the coal measures of Antarctica. It, thus, seems most reasonable to regard the rank of coal in the flat lying and relatively undisturbed deposits as essentially an indication of the extent of loading, or maximum overburden pressure, and the temperatures associated with loading at depth.

Present information seems to invite comparison of the Antarctic igneous sills with the Trias-Lias intrusives that characterize other Gondwana areas and terminate the Gondwanide deposition. According to S. H. Trevis of the OSU Institute of Polar Studies (personal communication, September 1961), the diabase near Mount Glossopteris is similar to some reported in South Africa by Walker and Poldervaart (1949).

Indirect evidence as to depth of loading in the Antarctic coal measures may be afforded by the intrusive diabase sills themselves (see Walker and Poldervaart, 1949, p. 688). The static load for Karroo dolerite sills injected into the Ecca (coal measures) series in South Africa is said to be from about 18,000 to 24,000 feet. Intrusion at shallower depths usually is associated with extrusive phenomena (Lombard, 1952) not yet recongnized in the Beacon series of Antarctica. In South Africa, this range of depth was sufficient to prevent vesiculation of the diabase; it may also explain why more of the altered coal deposits do not show vesicular coke structure. Natural coke apparently is more common in the South African coal fields than it is in Antarctica, and the coal in South Africa which is apparently unaltered by intrusived is considerable lower rank than any known to occur along the Antarctic escarpment. One is thus led to infer than the static load responsible for regional rank development of coal in the horst area of Antarctica may have been greater than 24,000 feet.

Most of the coal of the Gondwana areas of Australia, India, South Africa, and South America, which is not influenced by folding, overthrusting, or intrusion, is of bituminous rank. A few local deposits, possibly marginal in their basins of deposition, seem to be even lower rank. Thus, the coal of higher rank which is present along the Transantarctic escarpment may well indicate a greater relative depth of burial. If this high rank was induced prior to the period of igneous intrusion, it may indicate a very rapid and impressive amount of sedimentation during very late Paleozoic and early Mesozoic time. Available data do not provide an adequate basis for estimate of loading, but it does seem evident that the coal of the same age at the Amery locality, on the edge of the continent, has never carried over-burden to the same extent.

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Plate 1

Coniferous pollen grains from collections H-10 and H-22, coal measures, central range of the Horlick Mountains, Antarctica. All figures X 500.

Figures 1, 4, 8, 11a, 11b, 13 (?). Spore A. Accinctisporites (?) sp. (p. 11) Univesicate pollen.

Figures 2, 9, 10 (?), 12. Spore B. Accinctisporites (?) sp. (p. 12) Univesicate pollen.

Figures 3, 7. Spore D. Accinctisporites (?) sp. (p. 12) Univesicate pollen.

Figures 5, 6. Spore C. (p. 12). Univesicate (?), elliptical pollen or spores.

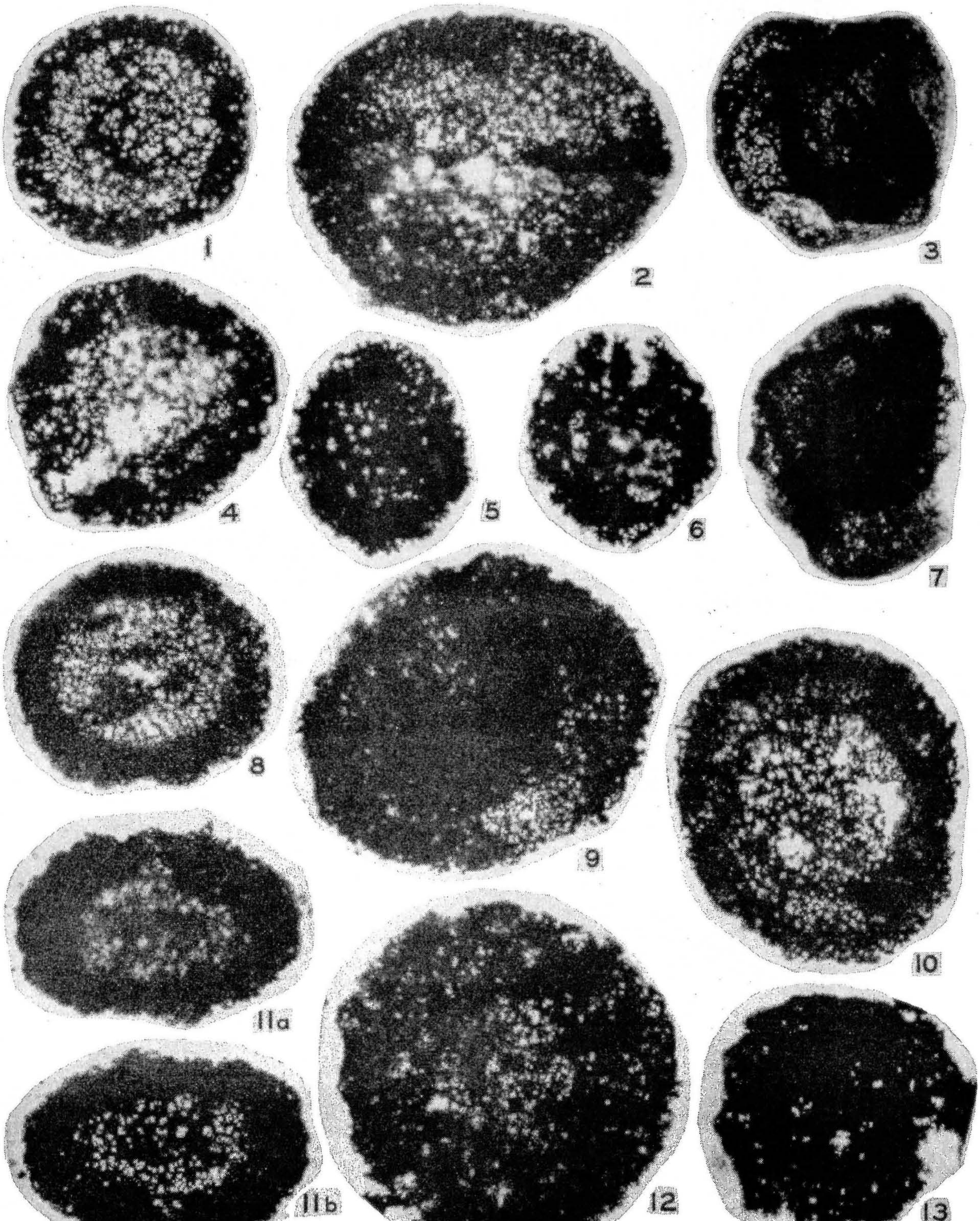

Plate 1

Plate 2

Coniferous pollen grains from collections H-10 and H-22, coal measures, central range of the Horlick Mountains, Antarctica. All figures X 500.

Figures 3, 5, 7, 10, 11, 13, and 14 are combined from two photos each, taken in slightly different planes of focus, to illustrate areas of irregularity more sharply.

Figures 1-4, 10 (?), 11, 16 (?). Spore E. (p 13). Parabivesicate pollen.

Figures 5, 12a, 12b. Spore G. Striatites (?) sp. (p 13). Parabivesicate pollen. Figure 5, lateral compression, cristate ridges wanting (?); figure 12a, b showing cristate ridges at two planes of focus.

Figures 6, 7. Spore F. (p 13). Parabivesicate pollen, with small sacci.

Figures 8, 15. Spore B. Accinctisporites (?) sp. (p 12). Univesicate pollen, large specimens.

Figures 9, 13 (?). Spore A. Accinctisporites (?) sp. (p 11). Univesicate pollen. The notch at the bottom of figure 13 is probably due to breakage in preparation. These specimens are very brittle.

Figure 14. Spore C. (p 12). Asymmetrically univesicate (?) pollen.

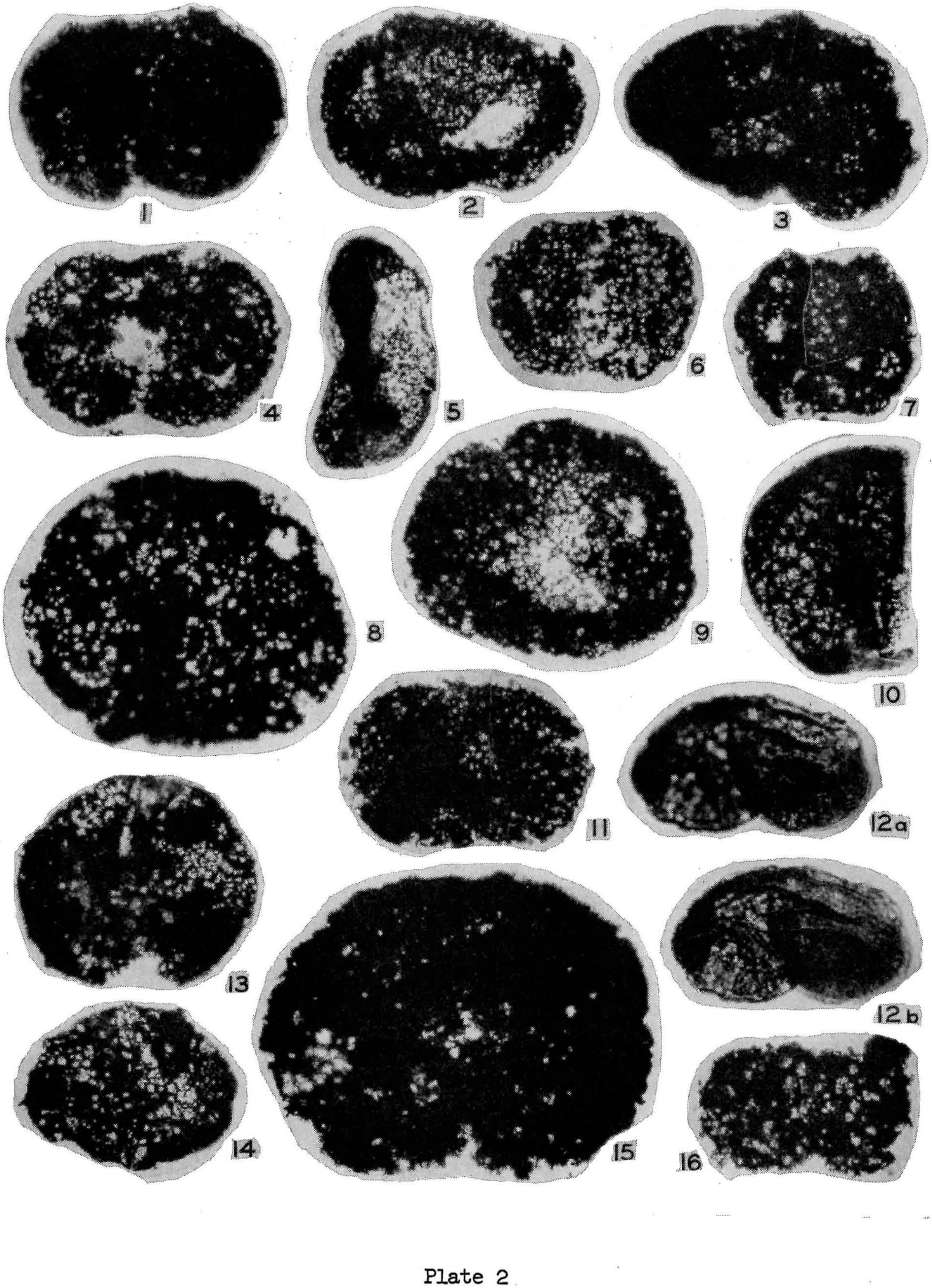

Plate 2

Plate 3

Pollen and spores from collections H-18 and H-22, coal measures, central range of the Horlick Mountains, Antarctica. Figures 1-7, X 500; figures 8-16, X 1000.

Figure 1. Spore H. (p. 15). Supratrivesicate (?) pollen.

Figure 2-6. Spore B. Accinctisporites (?) sp. (p. 12). Univesicate pollen. Figures 4 and 6 are both combined from two photos, each taken to show areas of irregularity in sharper focus.

Figure 7. Spore K. (p. 15). Univesicate pollen, with triangular central body.

Figure 8. Spore I. (p. 15). Parabivesicate pollen; note relatively small size.

Figure 9. Unidentified fossil. (p. 18).

Figure 10. Spore L. (p. 16).

Figure 11. Spore ? (p. 18).

Figure 12. Spore M. (p. 16). Note thick wall.

Figure 13. Spore N. (p. 16).

Figure 14. Spore O. (p. 16). One corner is broken.

Figure 15. Spore F (?). (p. 13). Parabivesicate pollen.

Figure 16. Spore P. (p. 16). Trilete (?).

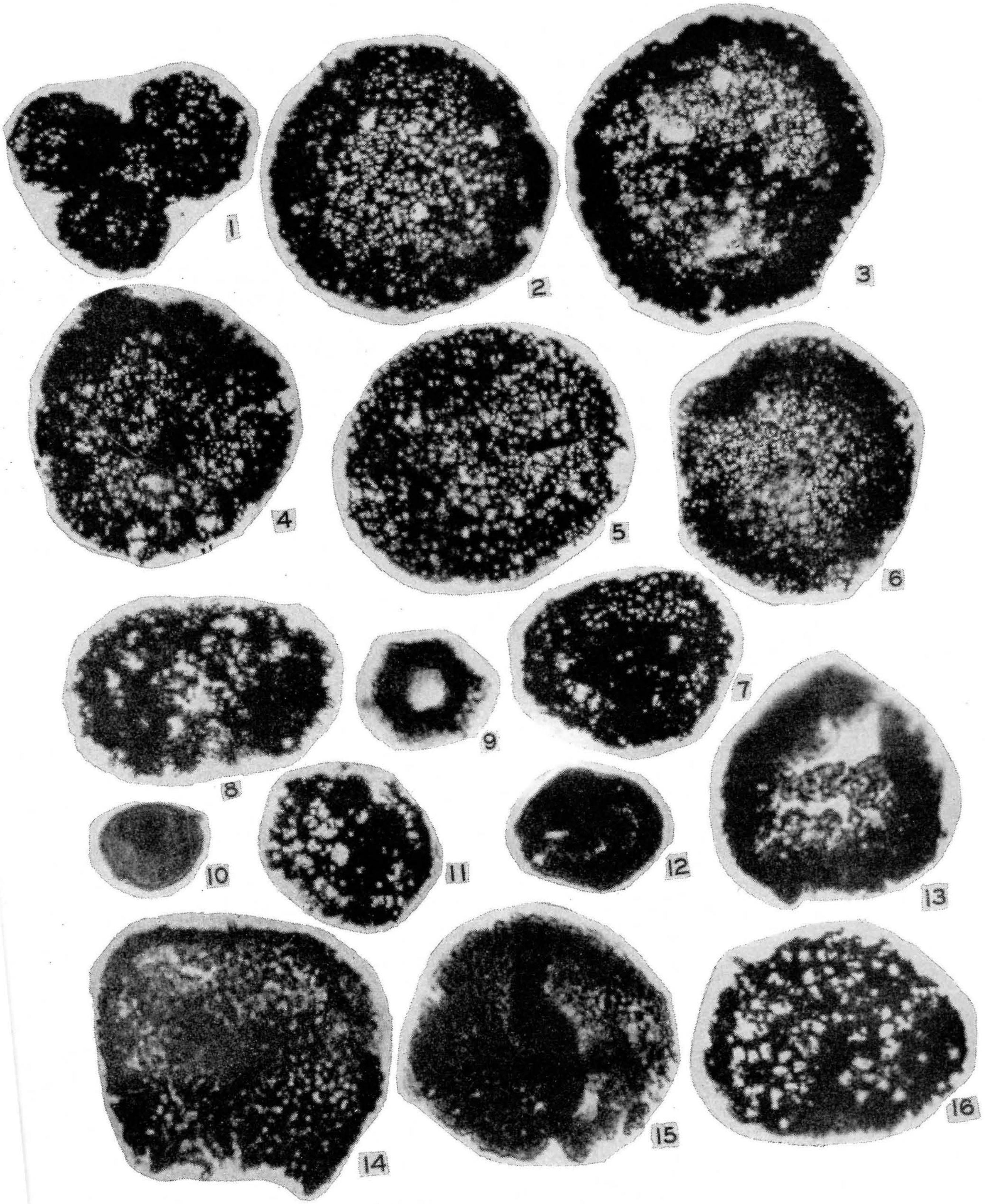

Plate 3

Plate 4

Pollen and spores from collections H-8, H-10, H-10-1/2, coal measures, central range of Horlick Mountains, Antarctica. Figures 1-7, and 15, X 500; figures 8-14, X 100.

Figures 1, 4 (?). Spore S. (p. 17). Trilete (?) spinose spore.

Figure 2. Spore O. (p. 16). Simple trilete spore.

Figure 3. Spore U. (p. 17). Trilete subtriangular spore.

Figure 5. Spore T. (p. 17). Characteristic sporelike object.

Figure 6. Spore B. Accinctisporites (?) sp (p. 12). Poorly preserved univesicate pollen grain (?).

Figures 7 (?), 12 (?). Spore N. (p. 16). Reticulate spore with zonal thickening. A fusain fragment obscures the lower portion on the right in figure 7. Example in figure 12 has been corroded in preparation.

Figure 8. Spore D. Accinctisporites (?) sp. (p. 12). Example smaller than usual, central body obscure but present.

Figure 9. Spore W. (p. 18).

Figure 10. Sporelike body (p. 18). Color, light yellow, unique; may be a contaminant specimen.

Figure 11. Attenuate spindle (p. 18). Dark reddish to yellowish translucent at the tip. May represent a corroded resinous inclusion.

Figure 13. Spore R. (p. 17). Simple triangular spore, one corner broken. Figure combined from two photos taken at slightly different planes of focus.

Figure 14. Spore K (?). (p. 15).

Figure 15. Spore C (?). (p. 12). Partly obscured by foreign body, X 500.

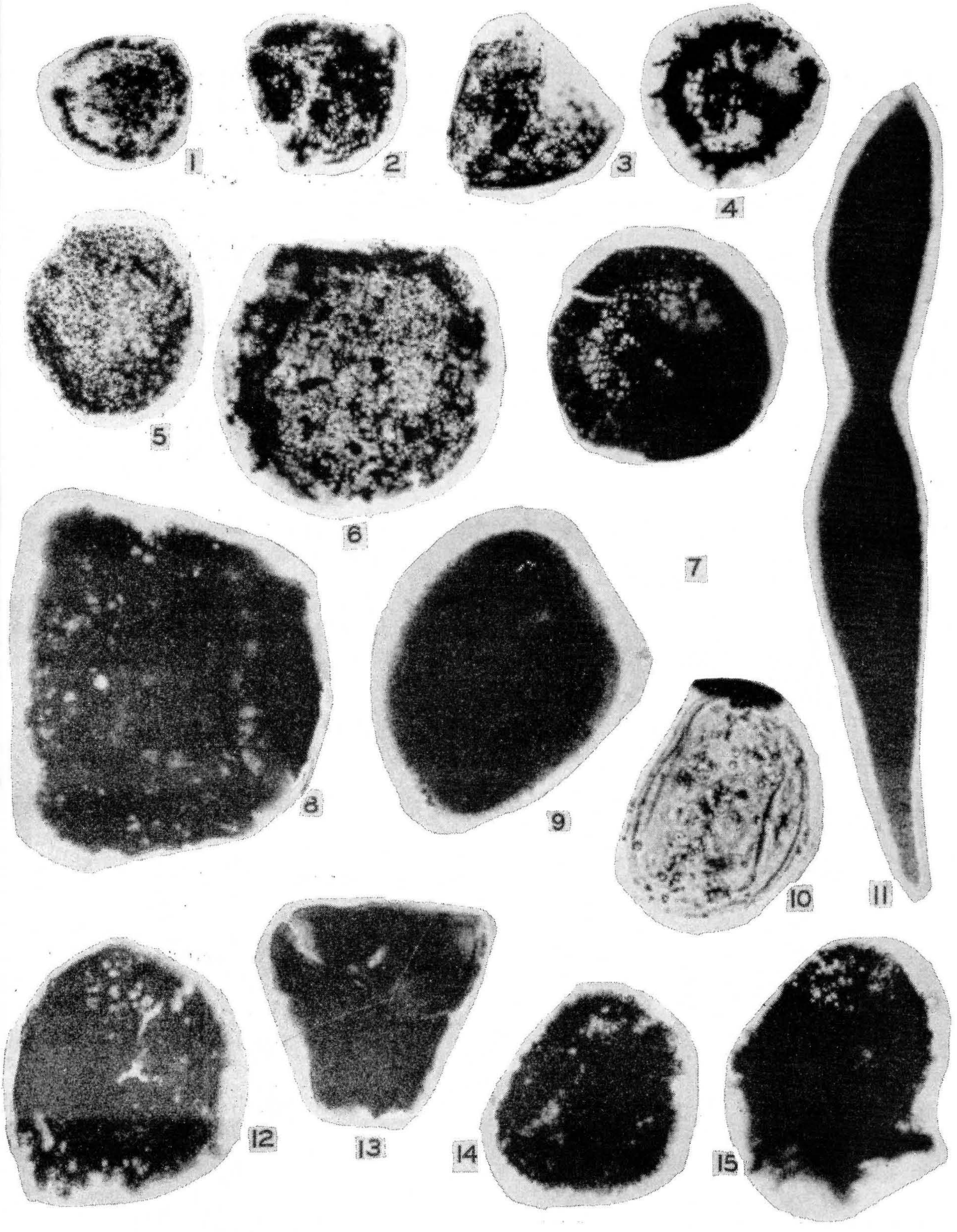

Plate 4

Plate 5

Fusain from coal measures sediments, central range of the Horlick Mountains, Antarctica. Figures 1-5, 7, X 500; figure 6, X 800; figure 8, X 1000; scale in millimeters shown below figures 9a and 9b.

Figure 1. (p. 18). Fusain fragment showing scalariform pitting characteristic of primary wood. Collection H-8.

Figure 2. (p. 18). Fusain fragment showing multiseriate bordered (?) pits. Collection H-22.

Figure 3. (p. 18). Semifusain fragment showing uniseriate bordered pits. Dark bars between adjacent pits seem to be a result of crowding and probably not bars of Sanio. Collection H-8.

Figure 4. (p. 18). Fusain fragment showing irregular spacing of bordered pits in radial walls of three tracheids. Collection H-10.

Figure 5. (p. 18). Fusain fragment showing radial view of wood ray at least 10 cells high, probably within the late wood zone of an annual ring. Collection H-8.

Figure 6. (p. 18). Semifusain fragment showing crowded multiseriate (araucarian) pitting on radial wall of tracheid. X 800. Collection H-8.

Figure 7. (p. 18). Fusain fragment showing crowded uniseriate pitting. Collection H-22.

Figure 8. (p. 18). Semifusain fragment with bordered pits. X 1000. Collection H-10.

Figure 9a. (p. 18). Fusinized woody fragment on rock matrix. Natural size. Collection H-14.

Figure 9b. (p. 18). Same as above, enlarged cracks of rectangular checking are largely occupied by secondary gypsum. X 2.

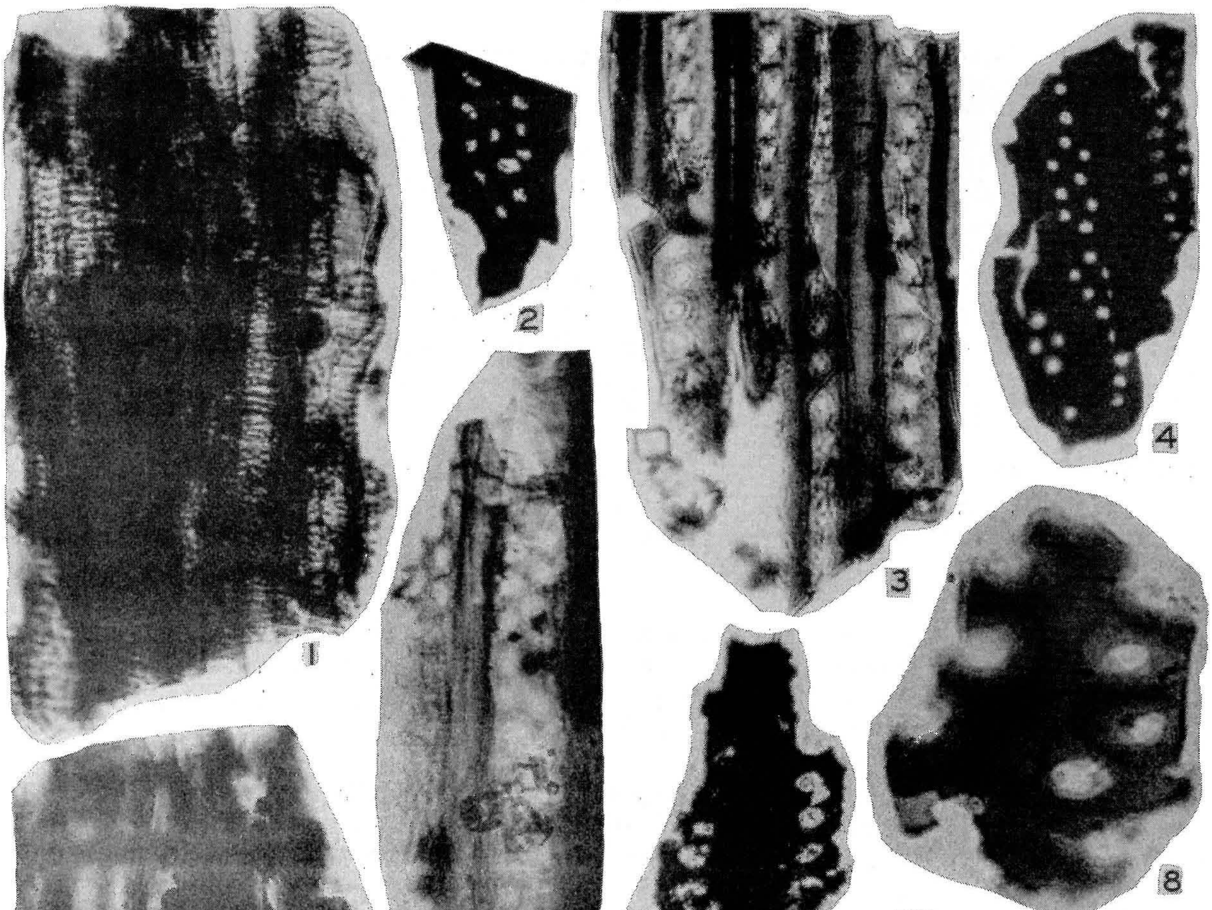

Plate 5

Plate 6

Woody stem (Antarcticoxylon sp.) from collection H-21, central range of the Horlick Mountains, Antarctica.

Figure 1. (p. 21). Secondary wood, peel section in radial plane, showing scattered pits and parts of three uniseriate (?) rays. X 200.

Figure 2. (p. 21). Secondary wood, peel section in transverse plane, showing compression folds and (near the top) an annual ring from the area marked "A" in figure 3. Figure consists of a mosaic prepared from seven photomicrographs following slightly varying focal planes of the section. X 100.

Figure 3. (p. 21). Transverse fracture surface of woody axis, lightly etched, showing compression banding fissures, and small area ("A") of better petrifaction where microsections were obtained. Natural size.

Figure 4. (p. 21). Secondary wood, peel section in tangential plane, showing uniseriate rays and reticulated, but nonpitted, tangential walls of tracheids. Bordered pits may be seen in section in radial walls of tracheids. X 200.

Figure 5. (p. 21). Detail of secondary wood along the growth ring in upper central area of section shown in figure 2. Frayed nature of lignin residue composing the remains of early and late wood is apparent. X 200.

Figure 6. (p. 21). As above, but from an area of annual ring which shows dense spacing of wood rays. Compression of early wood (above) is more evident at this magnification. X 200.

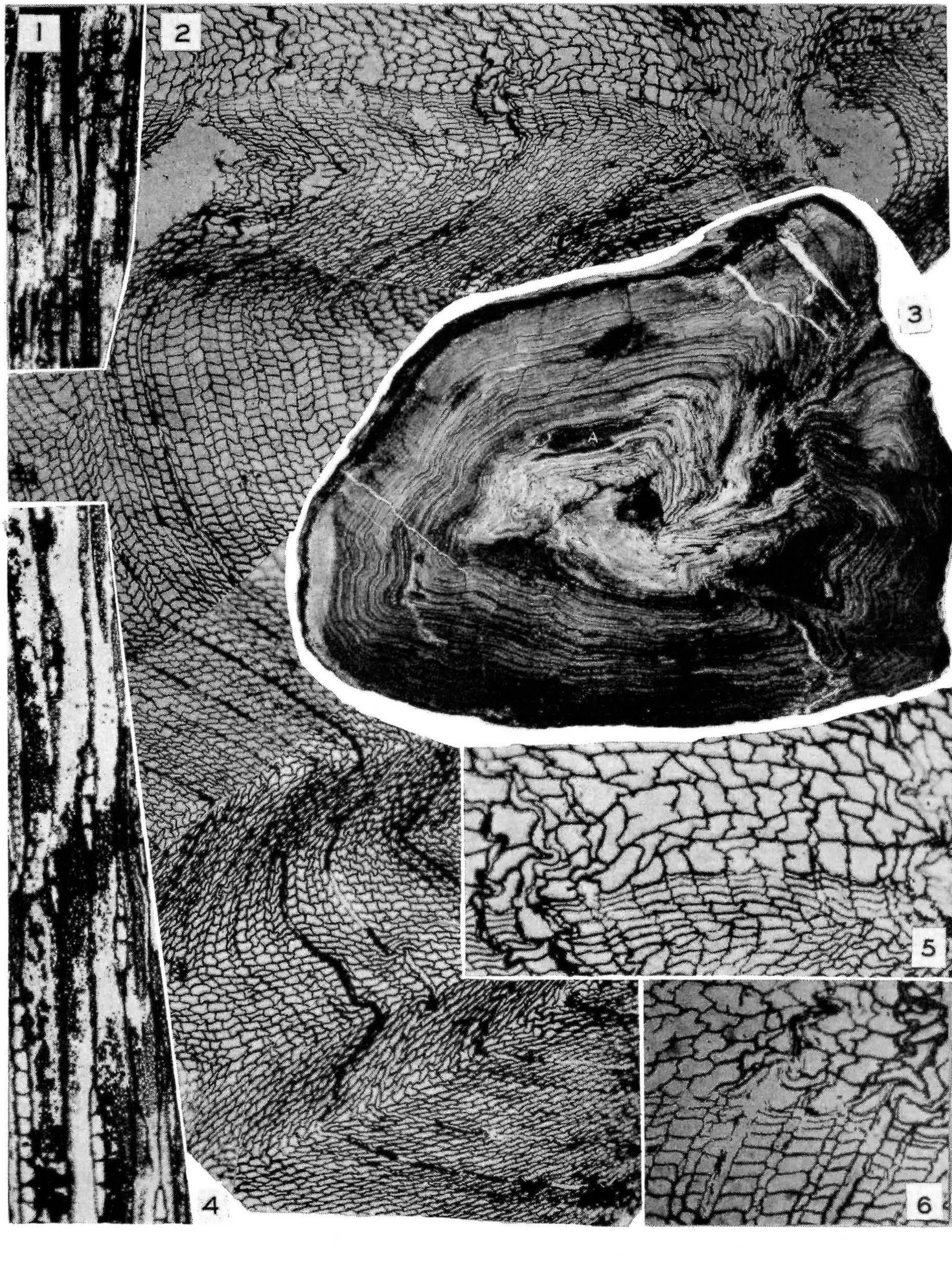

Plate 6

Plate 7

Longitudinal sections of woody stem (Antarcticoxylon sp.) from collection H-21, central range of the Horlick Mountains, Antarctica.

Figures 1-7a, X 500; figure 7b, X 1000.

Figure 1. (p. 21). Marginal ray cell, radial plane, showing pit fields.

Figure 2. (p. 21). Wood ray, radial plane, showing multiple pitting on cross fields.

Figure 3. (p. 21). Radial walls of secondary wood tracheids, showing crowded bordered pits.

Figure 4. (p. 21). As above, bordered pits less crowded.

Figures 5 and 6. (p. 21). As above, borders of pits somewhat better preserved.

Figures 7a, b. (p. 21). Radial walls of tracheid below and ray cell above showing reticulate appearance of lignin residue and the more common form of pit preservation. Figure 7b, X 1000.

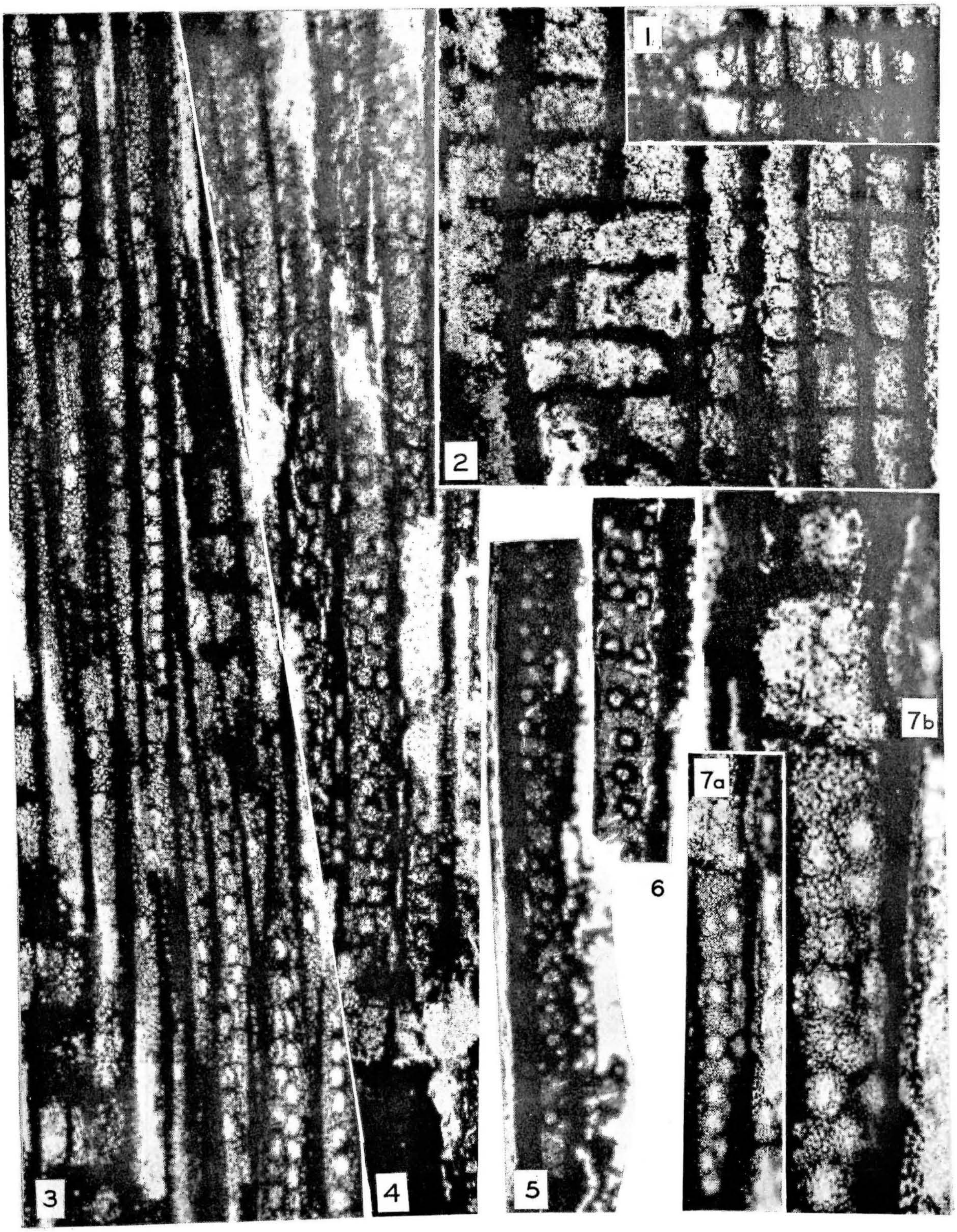

Plate 7

Plate 8

Transverse sections of wood of mixed petrifaction, collection H-19, central range of the Horlick Mountains, Antarctica. Figures 1-3, X 200; figure 4, X 500.

Figure 1. (p. 26). Secondary wood, in peel section, showing preservation of thick secondary walls in cells within limonitic islands (dark) and incomplete preservation of lignin skeletons of cells in lighter chalcedonic areas.

Figure 2. (p 26). As above, wood of chalcedonic areas more poorly preserved.

Figure 3. (p. 26). Annual ring, mostly preserved by limonite, late wood on the left, early wood on the right.

Figure 4. (p. 27). Peel section of secondary wood from limonitic area showing thick, probably swollen secondary walls, and poorly preserved central wall area. Cleavage seems indicated for mineral fillings of cell lumens.

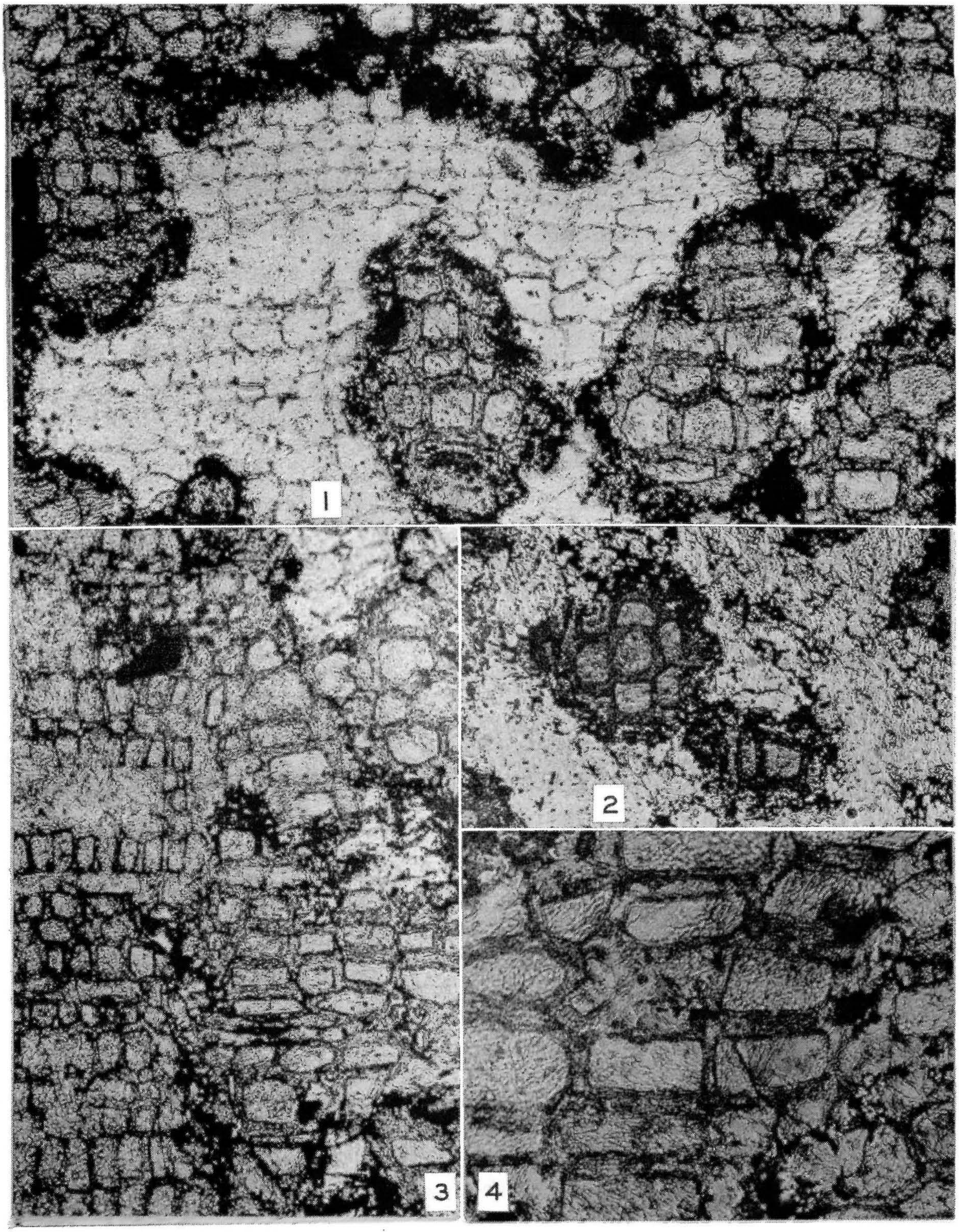

Plate 8

Plate 9

Friable wood in sandstone matrix, collection H-15, central range of the Horlick Mountains, Antarctica.

Figures 1 and 7. (p. 28). Polished transverse section secondary wood, carnauba infiltrated areas gray, photographed using vertical illumination. Uniseriate ray shown in figure 1; biseriate ray in figure 7. X 400.

Figure 2. (p. 28). As above, at higher magnification, showing details of cell wall preservation (dark). X 800.

Figures 3, 4, and 5. (p. 28). Polished transverse sections of secondary wood, carnauba infiltrated, vertical illumination. Rays evidently are biseriate, in part; more advanced degradation and distortion shown in figure 5. X 200.

Figure 6. (p. 27). Weathered surface showing friable wood with thick, annual rings enclosed in coarse-textured sandstone. Surface mould of checked wood fragment appears on the upper part of the sandstone specimen. X 1.1.

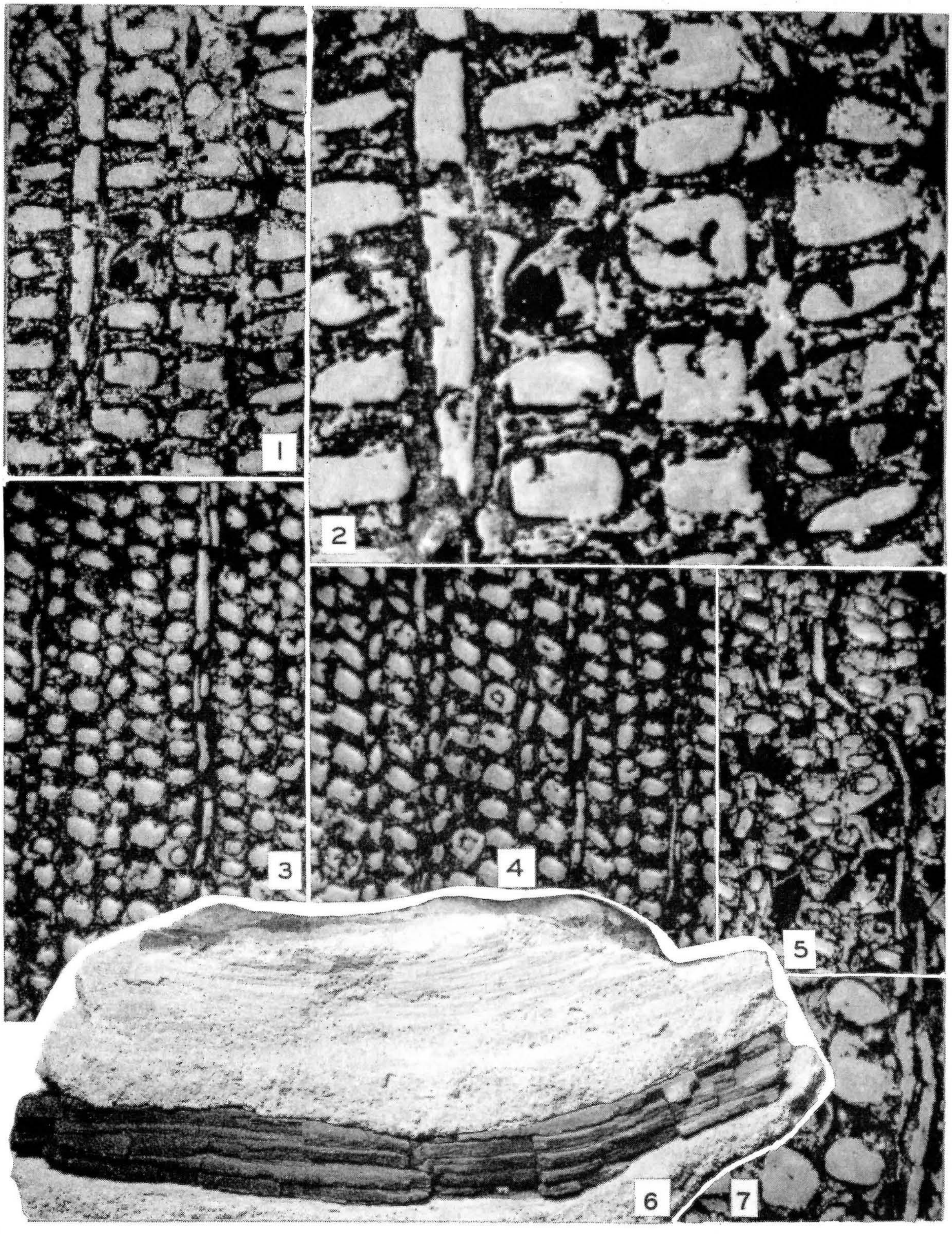

Plate 9

Plate 10

Friable wood in sandstone matrix, collection H-15, central range of the Horlick Mountains, Antarctica.

Figures 1-4. (p. 28). Polished surface sections in tangential plane of secondary wood, carnauba infiltrated (lumen) areas gray, photographed using vertical illumination. Mould impressions of bordered pits show well at the left in figure 2, and pit chambers appear in section in the right central part of figure 3. The characteristic denticulated outline centrally shown in figure 4 reflects details of cell wall irregularity but interpretation is difficult. All X 400.

Figures 5 and 8. (p. 29). Polished surface sections, carnauba infiltrated, radial plane of secondary wood showing ray cells with pit perforations in walls. An unidentified mineral (siderite ?) occurs in the area shown by intermediate gray tone in figure 8. X 400.

Figures 6 and 7. (p. 29). Polished surface sections, carnauba infiltrated, tangential plane of secondary wood, showing casts of pit apertures and fusiform terminations of tracheids. X 200.

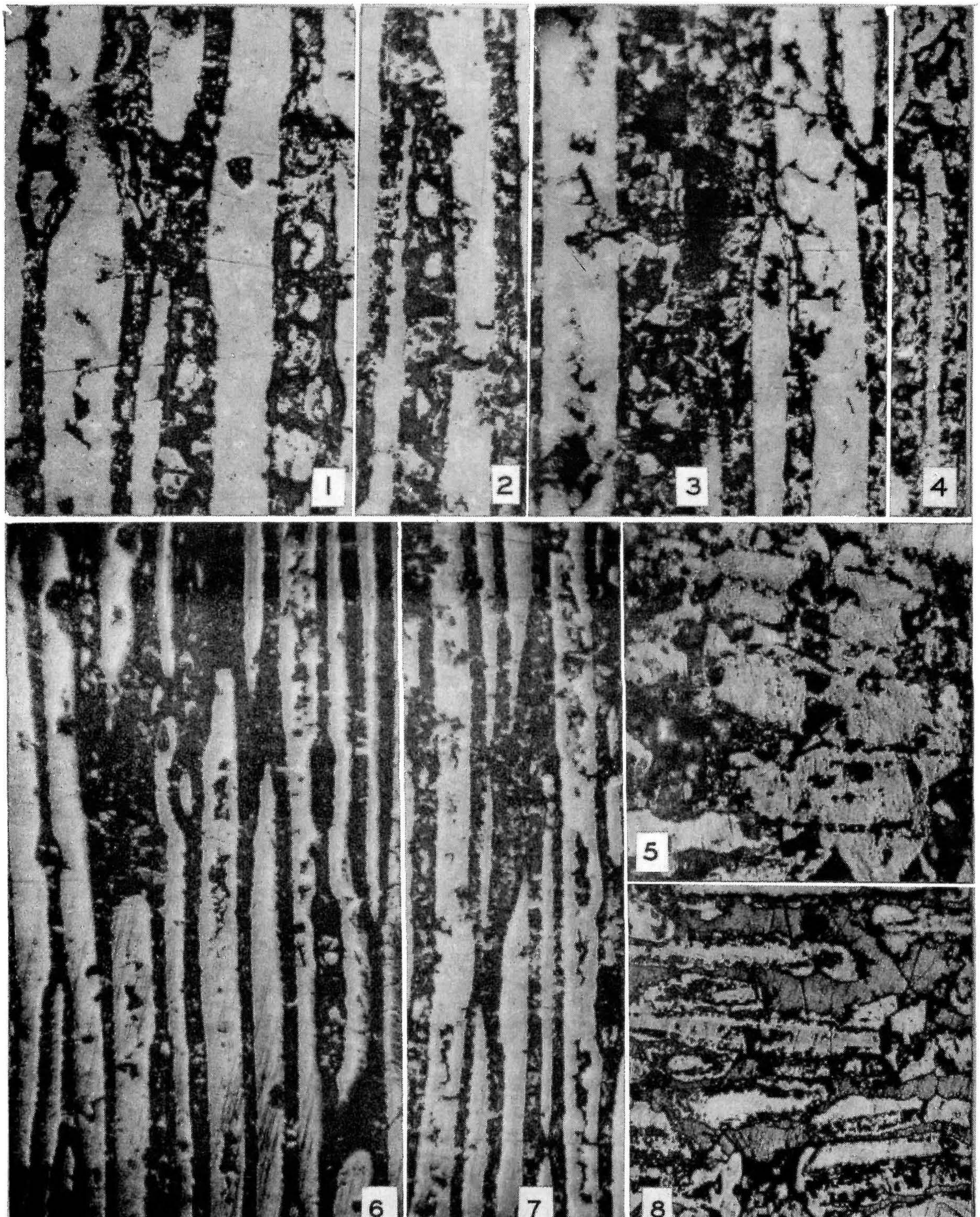

Plate 10

Plate 11

Leaves of plants and other fossils, central range of the Horlick Mountains, Antarctica.

Figures 1a, b. (p. 31). Glossopteris indica Schimper. Leaves showing venation. Striate lower surface shown by portions of both leaves in figure 1a; impression of smoother upper surface shown by specimens in 1b. Slightly enlarged, scales in millimeters.

Figures 2a, b, c. (p. 35). Arthrophyte (?) stem. Figure 2a shows axis in polished cross section. Band of cleated coal may be derived from a woody cylinder; lateral thickenings of cortex extend the full length of the specimen (11 cm). Depth of surface weathering shown by matrix which includes angular granules of coal. Collection H-23. Enlarged, scale in millimeters. Figure 2b shows contact of coaly cylinder and cortex (?) of the same stem, viewed in polished surface section (coal in light tone, mineral dark) by vertical illumination. X 200. Figure 2c shows cortex (?) with vestigial tissue structure. Network of coalified cell walls appear in lighter tone. X 400.

Figures 3 and 4. (p. 33). Samaropsis longii n. sp., seeds. X 5.

Figure 5. (p. 36). Invertebrate trails in coarse, flaky sandstone. Collection H-10-1/2. Slightly reduced, X 0.85.

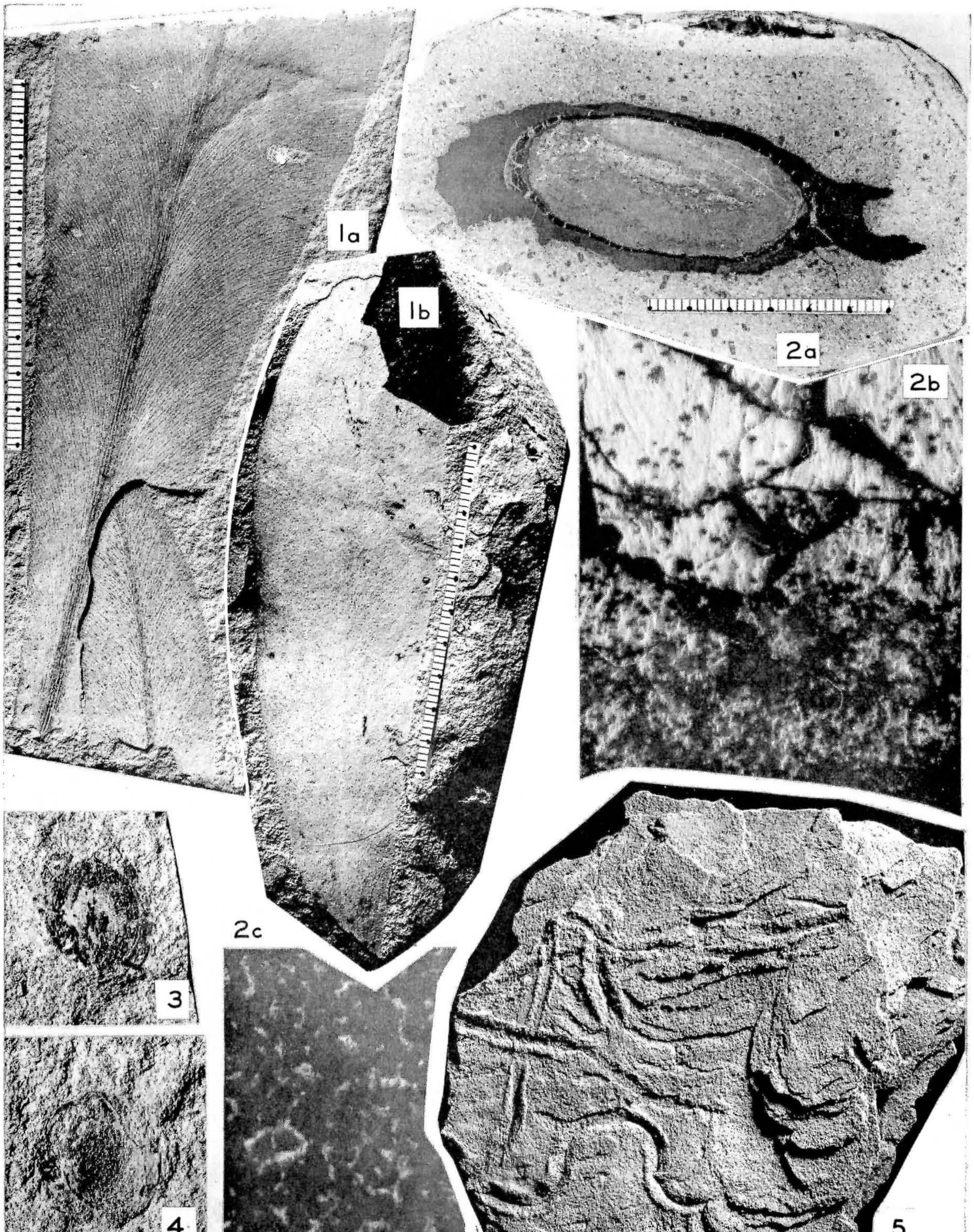

Plate 11

Plate 12

Lithologic features of coal from collection H-16, central range of the Horlick Mountains, Antarctica. Figures 1, 3-6, X 200; figure 2, X 2.5.

Figure 1. (p. 40). Vitrinite bands (gray), with very fine texture detrital mineral matter. Surface section, glycerine immersion, reflected light.

Figure 2. (p. 40). Polished surface of block, showing microbanded attrital character. Lighter gray lenticles are fusain.

Figures 3-6. (p. 40). Various textures shown by observation of surface section by reflected light with glycerine immersion. Dark areas represent mineral grains or aggregates. High reflectance of fusain is shown at the bottom of figure 4.

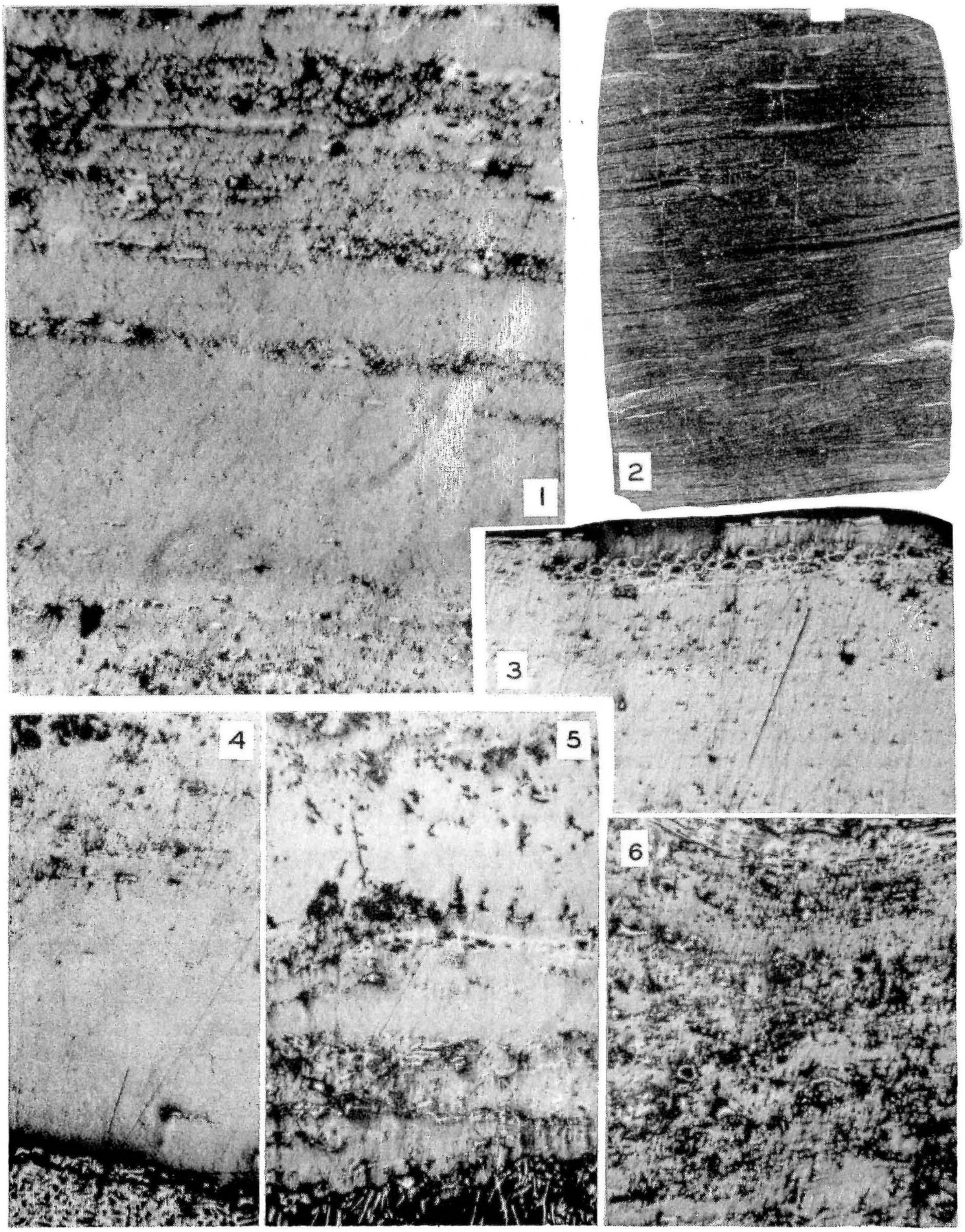

Plate 12

Plate 13

Microscopic features of coal from collection H-16, central range of the Horlick Mountains, Antarctica. Figures 1-7, X 200.

Figures 1-7. (p. 40). Fusain and semifusain, polished surface sections, glycerine immersion, reflected light. Figure 6 shows fusain from secondary wood in characteristically crushed condition; figure 4 shows similar structure with zone of late wood cells which have withstood compression and remain largely intact; figure 1 shows a similar zone of late wood in semifusain with evidence of plastic collapse of cells and distortion. Figures 2, 3, and 5 show woody tissue in semifusinized condition, some cells with humic filling (light) and others (showing better preservation of shape) mineral filled (dark). Semifusinite merges with vitrinite as shown by darker tone (lesser reflectance) in lower portions of figures 2 and 5. A more abrupt but irregular transition of fusinite and vitrinite is shown in figure 7, where separate and differently preserved plant fragments are in contact.

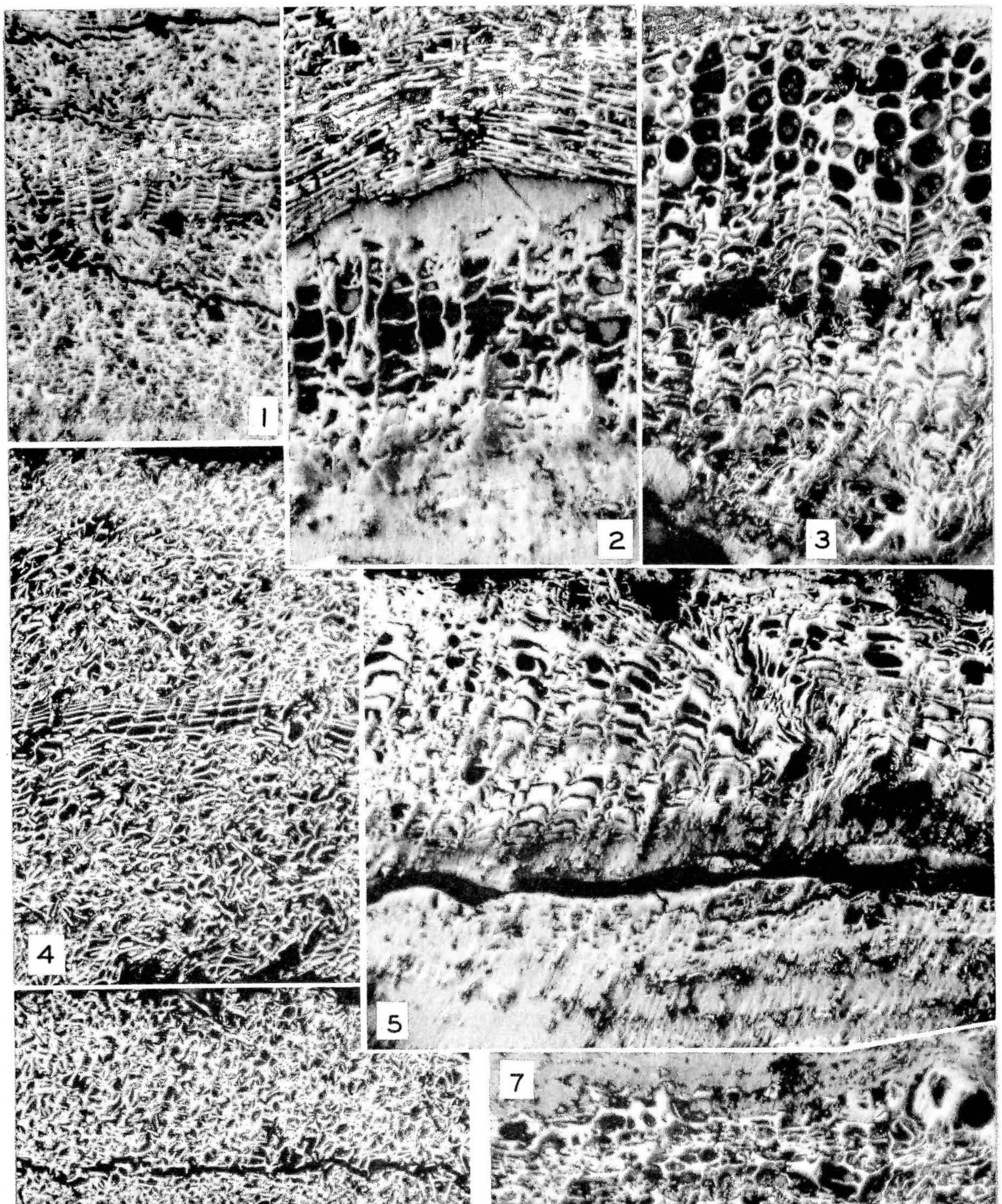

Plate 13

Plate 14

Lithologic features of coal from collection H-20, central range of the Horlick Mountains, Antarctica.

Figures 1 and 11. (p. 42). Attrital coal with rounded dispersed mineral granules, possibly kaolinite; thin sections, viewed by transmitted light. X 400.

Figure 2. (p. 40). Polished surface of block, showing thin and microbanded attrital character. Thin vitrain bands are fairly uniformly cleated. X 2.5.

Figure 3. (p. 41). Friable demineralized granule of impure coal showing abundant detrital resinous bodies. X 10.

Figure 4. (p. 41). Resinous bodies segregated from demineralized, impure coal. X 20.

Figures 5 and 8. (p. 41). Resinous bodies with variously deformed vacuoles, viewed in polished surface section, glycerine immersion, reflected light. X 200.

Figures 6 and 7. (p. 41). Coal viewed in thin section by transmitted light showing color differentiated cuticular strips in figure 6, and a resinous body with adjacent siliceous mineral matter in figure 7. The feather edge of the resinous body ($< 1\ \mu$ thick) shows yellowish to brownish translucence. The same types of structure in impure coal are shown according to different methods of observation in figures 7 and 8. X 400.

Figures 9 and 10. (p. 42). Small resinous bodies showing a marginal alteration (oxidation ??) zone, from impure attrital coal. Polished surface section, glycerine immersion, viewed by reflected light. X 400.

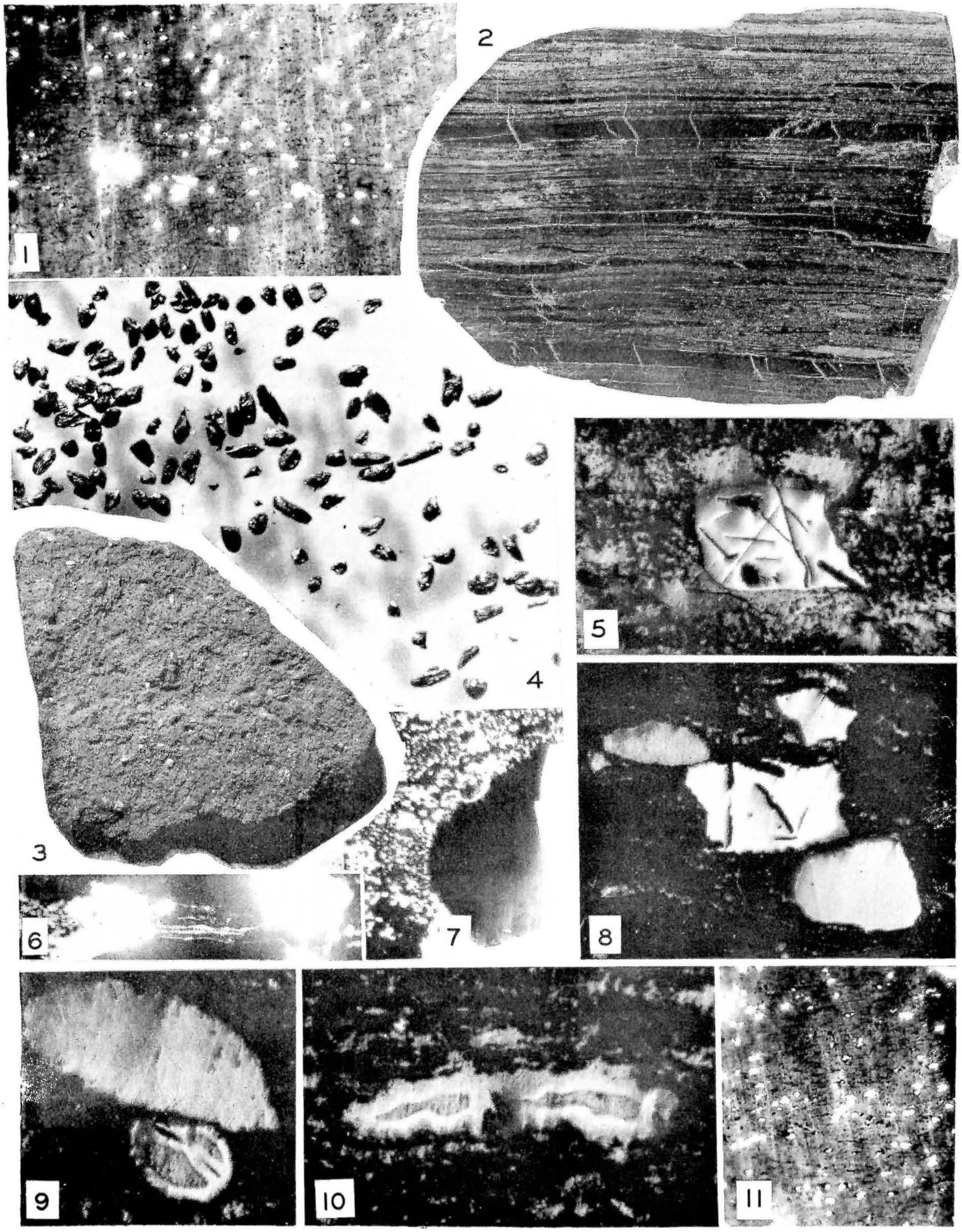

Plate 14

Plate 15

Microscopic features of coal from collection H-20, central range of the Horlick Mountains, Antarctica. Figures 1-10, X 200.

Figure 1. (p. 42). Vitrinite lamellae, specked by dispersed mineral granules, with detrital resinous body interspersed in a mineral-rich lamella. Polished surface section, glycerine immersion, viewed by reflected light.

Figures 2, 3, 4, 7, 9, 10. (p. 42). Various resinous bodies in mineral-rich matrix of impure attrital coal, showing range of size and configuration. Figure 4 also shows fusinite and vitrinite lamellae. Polished surface sections, glycerine immersion, viewed by reflected light.

Figures 5 and 8. (p. 42). Resinous bodies in mineral-rich matrix of impure attrital coal. Thin sections, viewed by transmitted light, for comparison with surface sections shown in other figures. Discrete mineral granules are more evident in thin sections; surface details of resinous bodies are more evident in surface sections.

Figure 6. (p. 42). Very fine-textured attrital coal (mostly translucent attritus) as shown by very thin section viewed by transmitted light. Coal of the same character is illustrated in a surface section at the same magnification in figure 1. The dark area, 3 or 4 microns thick, in the lower left hand corner of figure 6 is too dense to transmit light effectively; other portions shown are thinner.

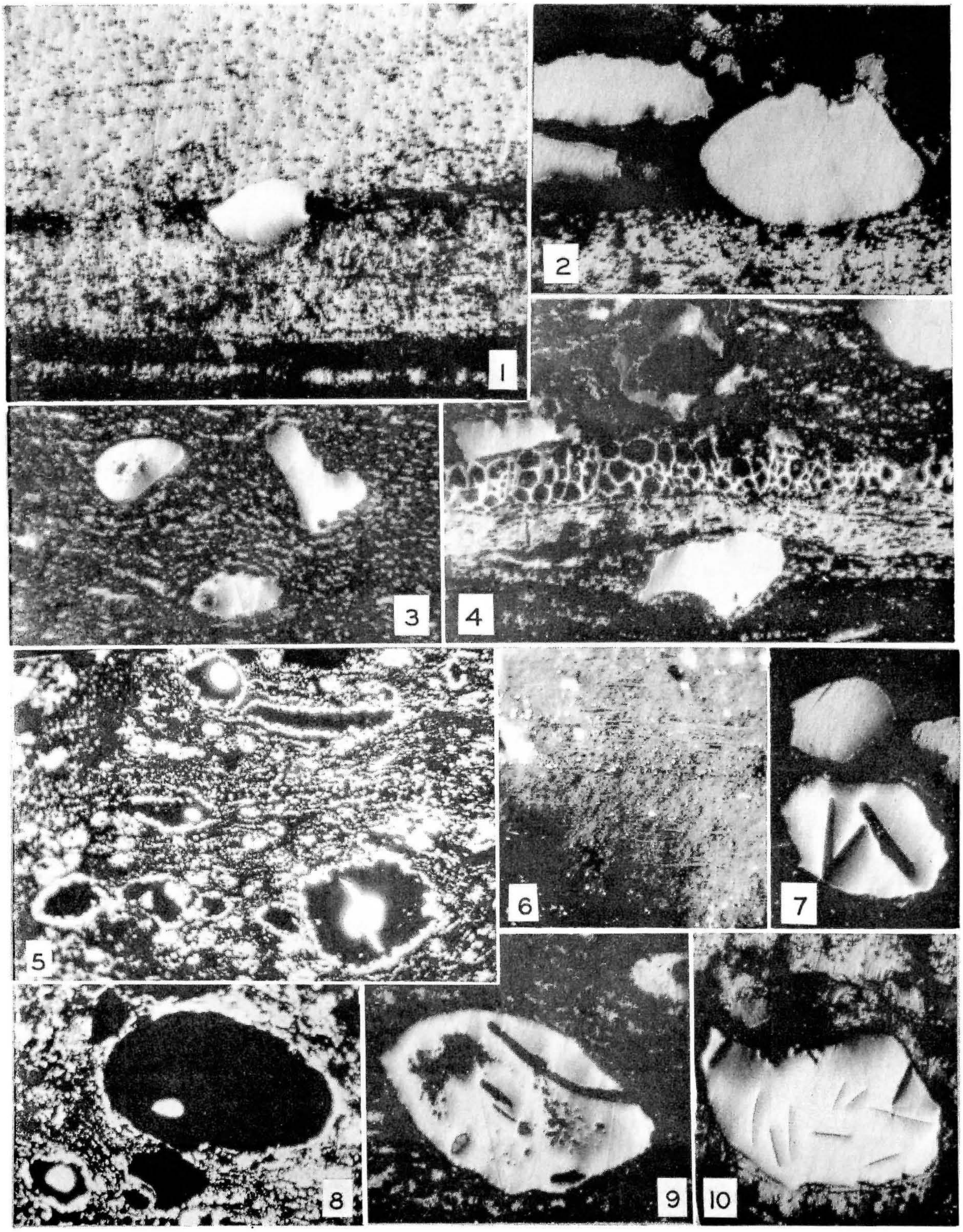

Plate 15